DEC 2 9 1981

I 19.42/4:78-138/supp.

ORIGINAL

REASSESSMENT OF THE EFFECTS OF CONSTRUCTION DEWATERING ON GROUND-WATER LEVELS IN THE COWLES UNIT, INDIANA DUNES NATIONAL LAKESHORE, INDIANA

COMPLETED
61

Supplement to Geological Survey
Water-Resources Investigations 78-138

Prepared in cooperation with the National Park Service

U. S. GEOLOGICAL SURVEY
OPEN-FILE REPORT 80-1105

REASSESSMENT OF THE EFFECTS OF CONSTRUCTION DEWATERING ON GROUND-WATER LEVELS IN THE COWLES UNIT, INDIANA DUNES NATIONAL LAKESHORE, INDIANA. SUPPLEMENT TO GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS 78-138

By Daniel C. Gillies and Wayne W. Lapham

U.S. GEOLOGICAL SURVEY

Open-File Report 80-1105

Prepared in cooperation with the
National Park Service

September 1980

I

CONTENTS

	Page
Metric conversion factors	vi
Abbreviations	vi
Abstract	1
Introduction	2
Purpose and scope	3
Review of data collected since 1977	4
Simulation of reduction of hydrostatic pressure in unit 3	15
Simulation of simultaneous construction dewatering and decline of seepage mound	17
Simulation of proposed mitigation	26
Discussion of and simulations related to the lateral variation of the hydraulic characteristics of the confining unit at Cowles Bog	27
Summary and conclusions	48
References	50

ILLUSTRATIONS

		Page
Figures		
1-6.	Maps showing:	
	1. Water levels in units 1 and 3 near NIPSCO Bailly site, August 14-16, 1978	5
	2. Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for steady-state conditions	6
	3. Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for experiment K, phase 1 dewatering	8
	4. Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for experiment U, phase 1 dewatering	9
	5. Water levels in units 1 and 3 near NIPSCO Bailly site, November 7, 1979	10
	6. Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for experiment U-7, phase 1 dewatering	11
7.	Graph showing model-simulated water-level declines at the NIPSCO-NPS boundary east of the excavation, for revised experiment S, phase 1 dewatering	16

ILLUSTRATIONS--Continued

Page

Figures

8-18. Maps showing:

8. Model-simulated water-level declines in unit 1 after 18 months of phase 2 construction dewatering (revised experiment U)..... 18
9. Model-simulated water-level declines in unit 3 after 18 months of phase 2 construction dewatering (revised experiment U)..... 20
10. Model-simulated water levels in unit 1 for simulated termination of fly-ash-pond seepage..... 22
11. Deviation of model-simulated water levels in unit 1 from "reference water levels" after 10 months of phase 2 construction dewatering (revised experiment U) and decline of seepage mound..... 24
12. Deviation of model-simulated water levels in unit 1 from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment U), decline of seepage mound, and mitigation at 200 gal/min..... 28
13. Deviation of model-simulated water levels in unit 1 from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment U), decline of seepage mound, and mitigation at 400 gal/min..... 30
14. Water levels in unit 1 near Cowles Bog, February 25-29, 1980..... 32
15. Maximum model-simulated water-level declines in unit 1 near Cowles Bog due to decline of seepage mound to equilibrium; with the "discontinuity" in the confining unit..... 35
16. Minimum model-simulated water-level declines in unit 1 near Cowles Bog due to decline of seepage mound to equilibrium; with the "discontinuity" in the confining unit..... 38
17. Maximum model-simulated water-level declines in unit 1 near Cowles Bog after 18 months of phase 2 construction dewatering (revised experiment S); with the "discontinuity" in the confining unit and continuous seepage from the fly-ash ponds..... 40
18. Minimum model-simulated water-level declines in unit 1 near Cowles Bog after 18 months of phase 2 construction dewatering (revised experiment S); with the "discontinuity" in the confining unit and continuous seepage from the fly-ash ponds..... 41

ILLUSTRATIONS--Continued

Page

Figure 19. Graph showing maximum model-simulated water-level declines in unit 1 at model node "11, 38" at Cowles Bog, due to phase 2 construction dewatering (revised experiment S); with the "discontinuity" in the confining unit and continuous seepage from the fly-ash ponds..... 42

20-23. Maps showing:

20. Maximum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment S) and decline of seepage mound; with the "discontinuity" in the confining unit..... 43

21. Minimum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment S) and decline of seepage mound; with the "discontinuity" in the confining unit..... 44

22. Maximum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" for phase 2 construction dewatering (revised experiment S), decline of seepage mound, and mitigation at 400 gal/min, at equilibrium; with the "discontinuity" in the confining unit..... 46

23. Minimum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" for phase 2 construction dewatering (revised experiment S), decline of seepage mound, and mitigation at 400 gal/min, at equilibrium; with the "discontinuity" in the confining unit..... 47

TABLES

Page

Table 1. Comparison of measured and simulated water-level declines caused by construction dewatering in USGS well 101 and in the south one-third of NIPSCO excavation: Phase 1 dewatering..... 13

2. Simulated water levels in south one-third of NIPSCO excavation for selected values of slurry-wall hydraulic conductivity: Phase 1 dewatering..... 14

3. Simulated effects of construction dewatering and decline of seepage mound on ground-water levels at Cowles Bog: Model node "11, 38"..... 36

METRIC CONVERSION FACTORS

Inch-pound units used in this report can be converted to metric units as follows:

Multiply inch-pound units	By	To obtain metric units
foot (ft)	0.3048	meter (m)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
mile (mi)	1.609	kilometer (km)

ABBREVIATIONS

Cowles Bog	Cowles Bog National Landmark.
ft	Foot.
ft/d	Foot per day.
gal/min	Gallon per minute.
Mgal/d	Million gallons per day.
Lakeshore	Indiana Dunes National Lakeshore.
NGVD	National Geodetic Vertical Datum of 1929.
NIPSCO	Northern Indiana Public Service Co.
NPS	National Park Service.
USGS	U.S. Geological Survey.
yr	Year.

REASSESSMENT OF THE EFFECTS OF CONSTRUCTION DEWATERING ON GROUND-WATER LEVELS IN THE COWLES UNIT, INDIANA DUNES NATIONAL LAKESHORE, INDIANA. SUPPLEMENT TO GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS 78-138

By Daniel C. Gillies and Wayne W. Lapham

ABSTRACT

A revision in the dewatering plan for the construction of a nuclear powerplant at the Northern Indiana Public Service Company's (NIPSCO) Bailly Generating Station and evidence suggesting the presence of a lateral variation in the hydraulic characteristics of the confining unit (unit 2) separating the unconfined sand aquifer (unit 1) and the confined sand aquifer (unit 3) in and near Cowles Bog National Landmark (Cowles Bog) have prompted a reassessment of the effects of construction dewatering on ground-water levels in the Indiana Dunes National Lakeshore (the Lakeshore). The revision in the construction dewatering plan involves pumping directly from unit 3 to reduce hydrostatic pressure within unit 3 and, thereby, prevent the uplift of the bottom of the excavation as it is deepened. Before revision, the plan basically involved pumping from unit 1.

Data collected near the construction site since December 1977 indicate that field conditions can be well simulated with a flow model that assumes the design value 2.8×10^{-4} feet per day for the hydraulic conductivity of the slurry wall around NIPSCO's excavation and a good hydraulic connection between the upper (unit 1) and lower (unit 3) aquifers under the south one-third of the excavation. Therefore, these hydrologic conditions were used in the model simulations for the reassessment of the effects of construction dewatering on ground-water levels in the Lakeshore.

Model results indicate that the revision in the dewatering plan produces water-level declines that do not differ significantly from those reported by William Meyer and Patrick Tucci in U.S. Geological Survey Water-Resources Investigations 78-138. The model results also indicate that the first phase of dewatering was very close to equilibrium after approximately 400 days.

A variation or "discontinuity" in the hydraulic characteristics of the confining unit (unit 2) beneath Cowles Bog would intensify water-level declines in unit 1 in the vicinity of Cowles Bog resulting from construction dewatering. With the "discontinuity," a simulation of simultaneous decline of the seepage mound and the second phase of dewatering indicates that water levels in unit 1 in Cowles Bog would be below "reference water levels" (water levels, as simulated in the model, that would have been present in unit 1 on October 26, 1976, if there had been no seepage from the fly-ash ponds) after 18 months. For a comparable simulation without the "discontinuity," water levels did not decline below the "reference levels." Model results with the "discontinuity" present also indicate that the artificial recharging of unit 1 near the excavation cannot completely make up water-level declines below

"reference levels" within the area of Cowles Bog after 18 months of simultaneous decline of the seepage mound and the second phase of dewatering. Because of the close proximity of the model boundary to the bog, model simulation can only yield maximum and minimum estimates of the impact of seepage-mound decline and construction dewatering for simulations of the "discontinuity" beneath Cowles Bog. The maximum and minimum estimates of impact are derived by simulating a constant-flux boundary and a constant-head boundary, respectively, at the east edge of the model. The difference between the maximum and minimum impacts is significant, particularly for simulation of seepage-mound decline, but the model cannot be used to determine which boundary condition best simulates the aquifer system. A new expanded model, which places the east boundary farther away from Cowles Bog to eliminate the effects of that boundary on water levels near the bog, would be needed to refine the estimates of the impact of construction dewatering and seepage-mound decline on water levels in the vicinity of the bog. Also, if possible, the storage properties of the marsh, which are not incorporated in the present model, could be included.

INTRODUCTION

In October 1979, the National Park Service learned of a fundamental revision in the dewatering plan for the construction of a nuclear powerplant (Nuclear 1) by Northern Indiana Public Service Company at its Bailly Generating Station, adjacent to the Indiana Dunes National Lakeshore. The plan for construction dewatering, as it existed from late 1977 to early 1978, and its estimated effects on ground-water levels in the Cowles Unit, Indiana Dunes National Lakeshore, were described by Meyer and Tucci (1979). In that report, construction dewatering at the NIPSCO Bailly Nuclear 1 site is divided into two phases. Phase 1 dewatering is designed to maintain the water level in the excavation at about 587 ft above the NGVD. Phase 1 dewatering was begun on March 17, 1977, and was still in progress on March 1, 1980. Phase 2 dewatering is designed to maintain the water level in the south one-third of the excavation in unit 1 at about 576 ft above the NGVD for 18 months.

The revision in the construction dewatering plan involved pumping directly from the confined sand aquifer (unit 3), underlying the excavation site, to reduce hydrostatic pressure within unit 3 and, thereby, prevent the uplift of the bottom of the excavation as it is deepened. Before revision, the plan basically involved pumping from unit 1. The need for reduction in hydrostatic pressure and a description of the proposed dewatering system are detailed in a report submitted by NIPSCO to the Nuclear Regulatory Commission (Sargent and Lundy, 1979).

NIPSCO's current plans for improving the coal-fired generating plant include sealing the fly-ash ponds between spring and autumn of 1980. As a result, seepage from the fly-ash ponds will cease and the ground-water mound underlying the ponds will begin to decline. Because of overlapping construction schedules, intensified dewatering of the south one-third of the excavation (phase 2) and the decline of the seepage mound may occur simultaneously.

Although decline of the seepage mound and construction dewatering were simulated in separate model experiments, their simultaneous occurrence was never simulated in the study by Meyer and Tucci (1979).

To maintain ground-water levels within the Lakeshore during construction dewatering, NIPSCO has designed the mitigation (artificial recharge) program described by Sargent and Lundy (1978). This program uses a trickling-filter recharge system to inject water into unit 1 between the excavation and the NIPSCO-NPS boundary when mitigation is necessary. The effect of mitigation was not considered by Meyer and Tucci (1979).

The USGS and the NPS have collected new hydrologic data in the vicinity of Cowles Bog. These data suggest that (1) the confining unit (unit 2), normally present between the unconfined aquifer (unit 1) and the confined aquifer (unit 3), may be thin or absent; (2) the vertical hydraulic conductivity of unit 2 may be greater than it is elsewhere; or (3) a combination of items (1) and (2) may exist in the area of the bog. This "discontinuity" in the confining unit would greatly enhance the hydraulic connection between the unconfined and confined aquifers and could intensify the impact of construction dewatering on water levels at Cowles Bog, particularly if a large part of the water pumped from the excavation came from unit 3.

Purpose and Scope

Because of the new information discussed in the preceding paragraphs, NPS requested that the USGS reassess the effects of construction dewatering on water levels within the Lakeshore boundary. The USGS began the present investigation in December 1979. The objectives of the study were to (1) review all significant hydrologic data collected at the NIPSCO Bailly site since the study by Meyer and Tucci (1979) and determine whether the data could be used to refine their estimates of effects of construction dewatering on ground-water levels in the Lakeshore, (2) estimate the impact of NIPSCO's proposed hydrostatic pressure reduction in the confined aquifer beneath the excavation on ground-water levels in the Lakeshore, (3) simulate simultaneous phase 2 construction dewatering and decline of the seepage mound, (4) test the hydrologic feasibility of NIPSCO's proposed mitigation, and (5) simulate a "discontinuity" in the confining unit (unit 2) at Cowles Bog and assess its effect on water-level declines caused by construction dewatering.

Because the current report is a supplement to the one prepared by Meyer and Tucci (1979) and, therefore, references that report extensively, a detailed understanding of the 1979 report is necessary for an understanding of the current report. The term "model-simulated" used in this supplementary report is the same as "model-derived" used in Meyer and Tucci (1979).

REVIEW OF DATA COLLECTED SINCE 1977

When model experiments K through Z were done by Meyer and Tucci (1979, p. 69 to 94), water had been pumped from NIPSCO's excavation for only 9 months. Furthermore, Meyer and Tucci (1979, p. 75) assumed that phase 1 dewatering would continue only until August 1978, at which time phase 2 dewatering would begin and would continue for 18 months. They also assumed that seepage from the fly-ash ponds would continue at the model-simulated rate of 1.96 Mgal/d throughout the duration of construction dewatering. However, the start of phase 2 dewatering has been delayed by more than 18 months, and phase 1 dewatering has continued in the interim. Throughout the prolonged phase 1 dewatering, withdrawals of water from the excavation have been metered, and water levels have been regularly measured in observation wells near the excavation and in the adjacent Lakeshore. The average pumping rate for removal of water from the excavation from March 17, 1977, through August 1, 1978, was 245 gal/min. In the model experiments of Meyer and Tucci (1979), the simulated rate for phase 1 dewatering was 280 gal/min. The rates differ because Meyer and Tucci had to estimate the rate of pumping for the last 7 months of phase 1 (January through July 1978) so that the average pumping rate could be used in their model simulations. However, the simulated pumping rate and the actual pumping rate are close enough so that a reasonable comparison can be made between water levels for phase 1 dewatering, as simulated by Meyer and Tucci (1979), and water levels measured in the field on or about August 1, 1978. These comparisons were made to determine which of the model experiments (K-Z) best simulated conditions subsequently observed in the field. Seasonal fluctuation should not interfere significantly with these comparisons because natural ground-water levels observed in August 1978 were within about 0.5 ft of those observed in October 1976, the calibration period for the Meyer and Tucci model, whereas differences in simulated water-level changes among experiments K through Z are much greater.

Water levels in units 1 and 3, August 14-16, 1978, are shown in figure 1. This period was the one closest to the end of phase 1 dewatering in model experiments K through Z for which complete water-level data were available. The effect of pumping from the excavation is evident in both water-level maps in figure 1 by the curvature of the water-level contours around the south end of the excavation, particularly for unit 3. The water level in the excavation for unit 1 was measured in a well inside the slurry wall near the southeast corner of the excavation. (For well location, see Meyer and Tucci, 1979, fig. 18, p. 42.) The water level under the south one-third of the excavation for unit 3 is the average of measurements by NIPSCO pneumatic piezometers P-1 through P-5, which were installed by NIPSCO in June 1978 (Sargent and Lundy, 1979). The installation of the pneumatic piezometers is discussed in detail in Northern Indiana Public Service Company (1978). Until these piezometers were installed, measurement of the water level in unit 3 beneath the excavation was not possible. Comparison of water levels in units 1 and 3 measured in August 1978 (fig. 1) with model-simulated water levels in units 1 and 3 for steady-state model calibration (fig. 2) further illustrates how pumping from the excavation has affected the ground-water system. In the south one-third of the excavation, the water levels in both units 1 and 3 have declined about 11 ft. The nearly equal water-level decline in the two

BEST DOCUMENT AVAILABLE

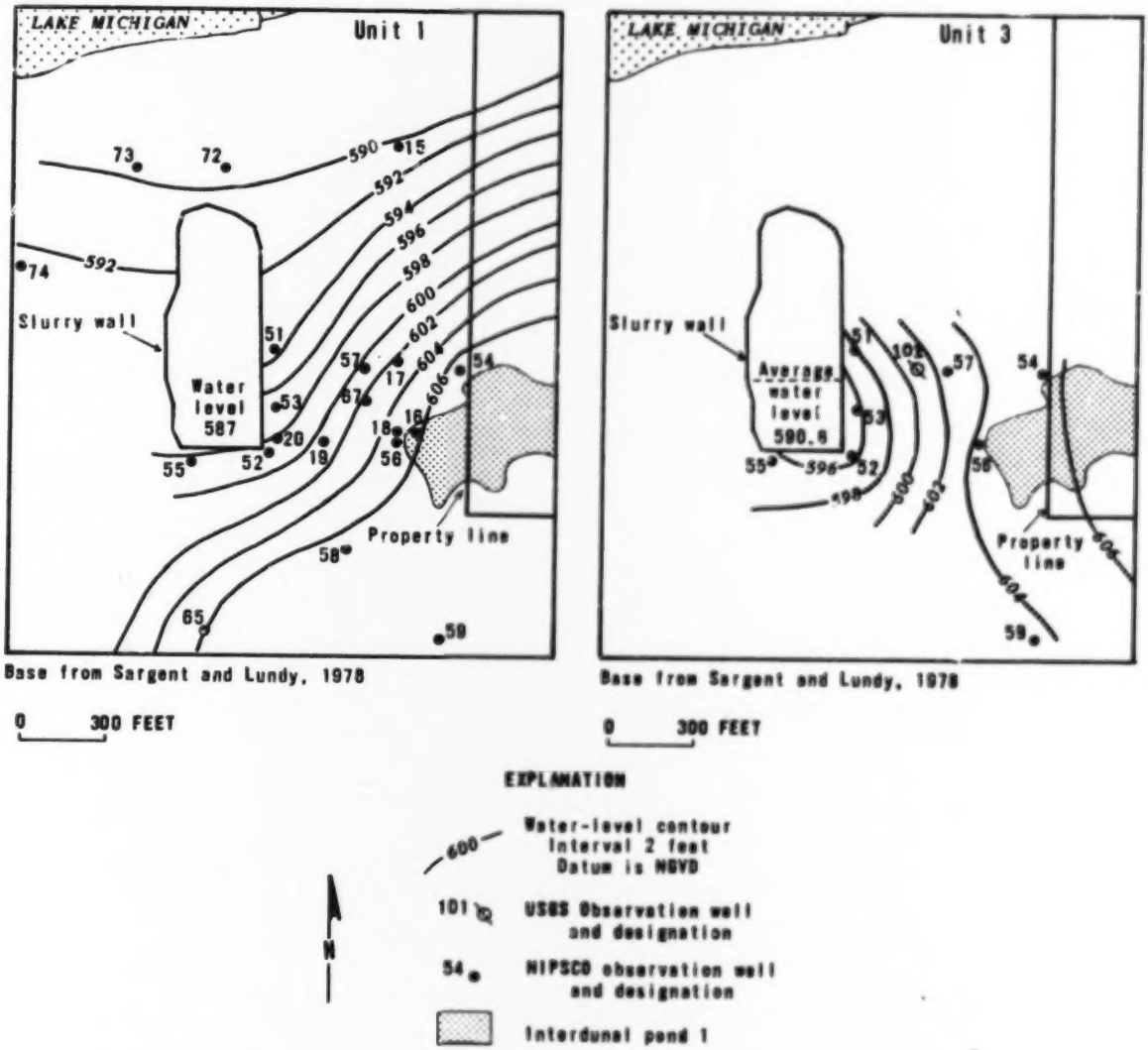


Figure 1. -- Water levels in units 1 and 3 near NIPSCO Bailly site, August 14-16, 1978.

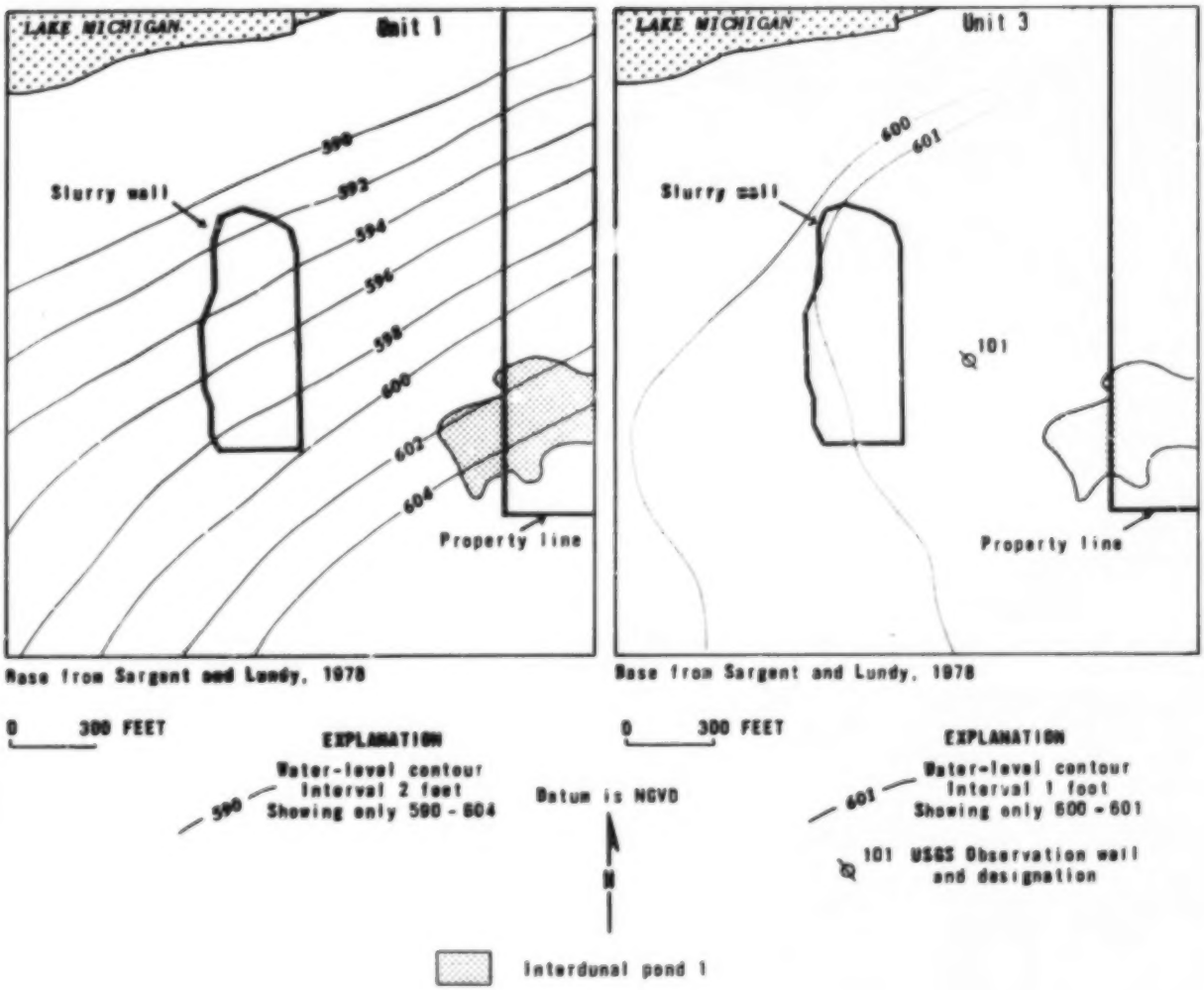


Figure 2.-- Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for steady-state conditions (simulated by Meyer and Tucci, 1979).

BEST DOCUMENT AVAILABLE

units also suggests that the hydraulic connection between the two aquifers is good in that area, especially because little water has been removed directly from unit 3. The significance of this hydraulic connection was investigated further by examining the results of phase 1 dewatering for model experiments K through Z of Meyer and Tucci (1979).

Model experiments K tnrough Z can be divided into two major groups on the basis of the hydraulic properties of the excavation site simulated. In experiments K through R, the slurry wall surrounding the excavation was simulated as very leaky, and the confining unit (unit 2) between units 1 and 3 under the south one-third of the excavation was simulated as continuous and tight. In experiments S through Z, the slurry wall was simulated as having a design hydraulic conductivity of 2.8×10^{-4} ft/d, which is tight relative to experiments K through R. Unit 2 under the excavation was simulated as discontinuous and leaky. (See Meyer and Tucci, 1979, tables 3 and 4.) The storage coefficient for unit 1 in these experiments had little or no effect on model-simulated water levels because equilibrium is virtually reached before the end of simulated phase 1 dewatering. The overall vertical hydraulic conductivity of unit 2 also had little effect on model results for the range of values simulated.

The effects of pumping in the south one-third of the excavation for the model experiments that produced maximum and minimum water-level declines in units 1 and 3 for groups K-R and S-Z, as well as two sets of field measurements, are shown in table 1. Because the coefficient of storage of unit 1 had little or no effect on simulated water levels after phase 1 for experiments K through Z, the result of each of the other 8 experiments is virtually identical with the result obtained with the same slurry wall hydraulic conductivity and vertical hydraulic conductivity of unit 2 but a different coefficient of storage of unit 1 (Meyer and Tucci, 1979, p. 76 and 84). Therefore, none of the other 8 experiments is included in table 1. Model-simulated and estimated water-level declines for USGS well 101 are also shown in table 1. Table 1 indicates that experiments S through Z produced declines in unit 3 much closer to the field-estimated declines than experiments K through R produced. Also, the differences in water levels between units 3 and 1, simulated in experiments S and U, are closer to the differences calculated from field-measured values than the differences produced by experiments K and Q. Comparison of the field data with model-simulated data in table 1 indicates that simulation of a tight slurry wall and a leaky unit 2 under the excavation (as in experiments S and U), are the best simulation of the system. This conclusion is further supported by the simulated water levels for experiments K and U shown in figures 3 and 4, respectively. When compared with the measured water levels in figure 1, water levels produced by experiment K show too much effect of phase 1 dewatering on unit 1, most likely because of the leaky slurry wall, and too little effect on unit 3, most likely because of the tight unit 2 under the excavation. Experiment U, however, produced water levels in units 1 and 3 more like those measured in August 1978. A similar correlation between measured and simulated water levels is shown by figures 5 and 6. Water levels measured in units 1 and 3 in November 1979 are shown in figure 5. Model-simulated water levels in units 1 and 3 for experiment U-7 are shown in figure 6. Experiment U-7 is the same as experiment U

BEST DOCUMENT AVAILABLE

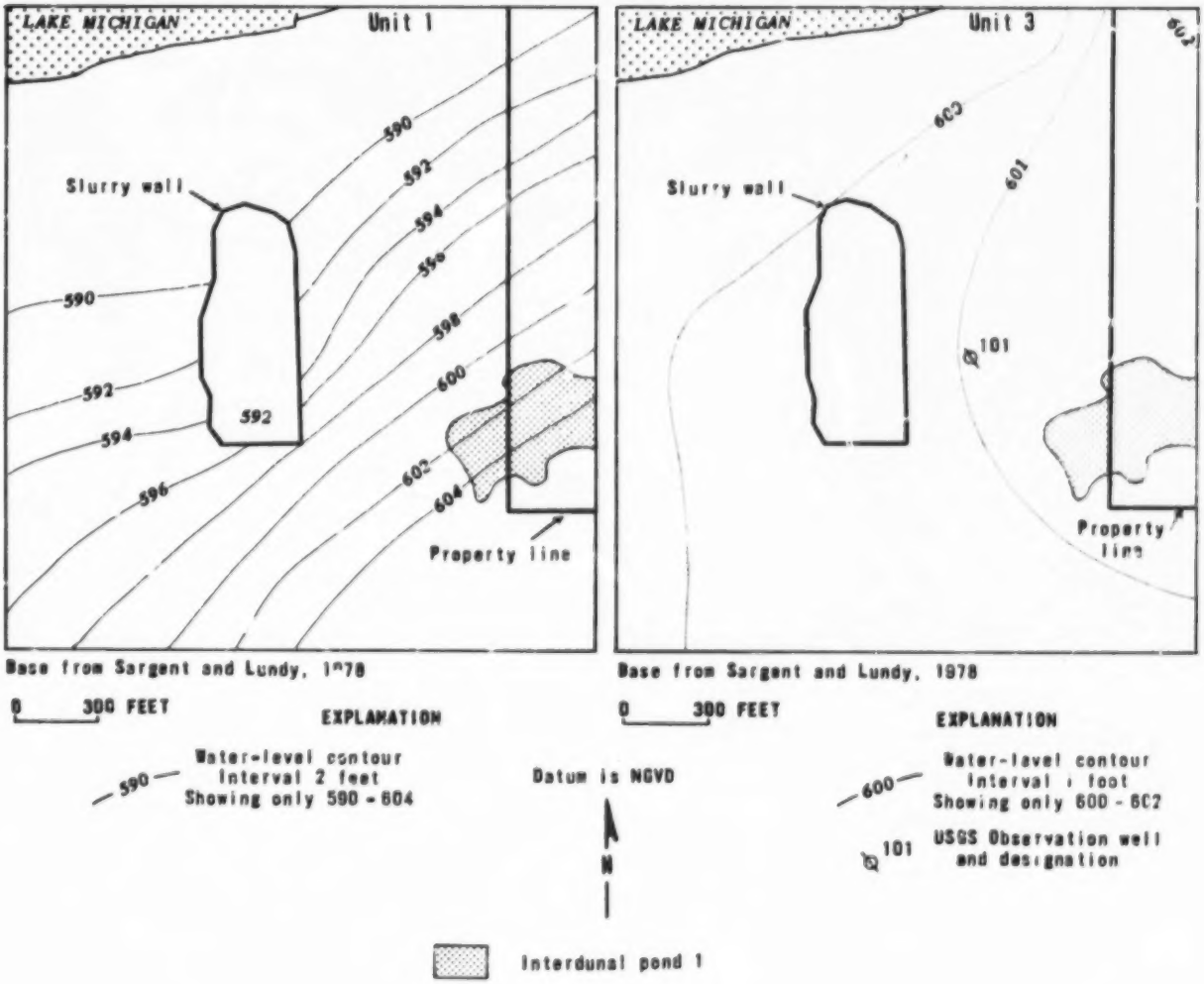


Figure 3.-- Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for experiment K, phase 1 dewatering (simulated by Meyer and Tucci, 1979).

BEST DOCUMENT AVAILABLE

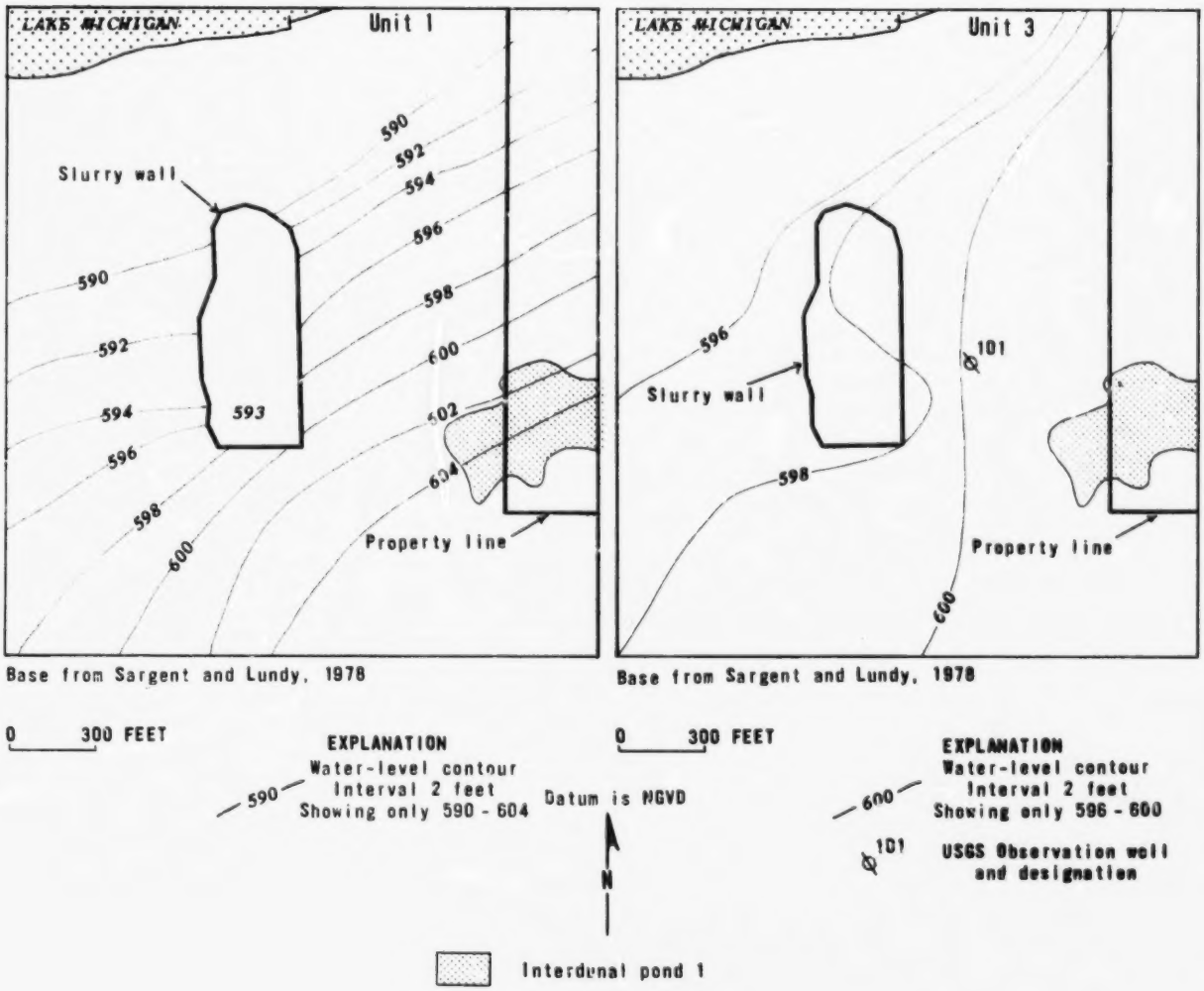


Figure 4.-- Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for experiment C, phase 1 dewatering (simulated by Meyer and Tucci, 1979).

BEST DOCUMENT AVAILABLE

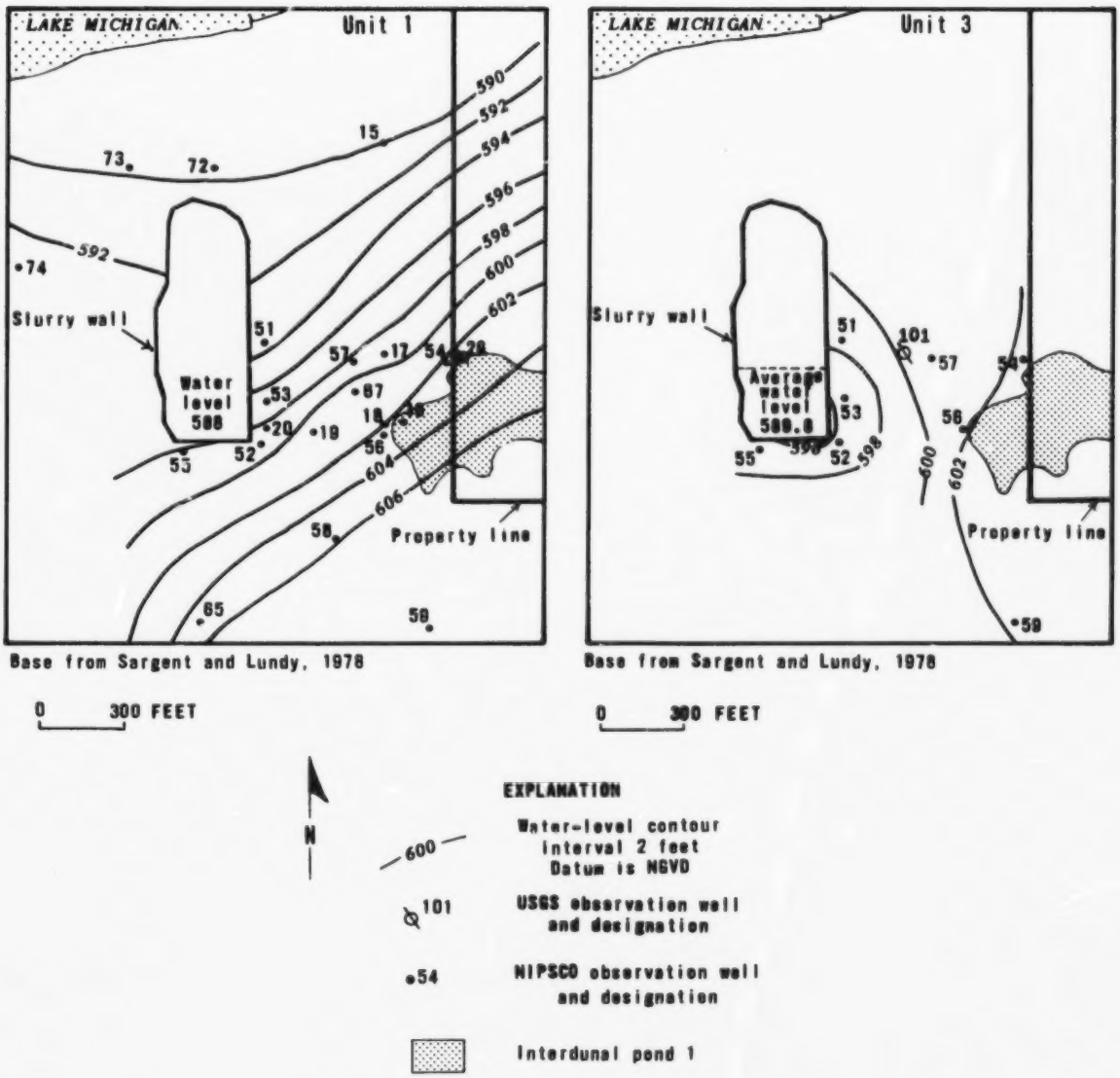


Figure 5. -- Water levels in units 1 and 3 near NIPSCO Bailly site, November 7, 1979.

BEST DOCUMENT AVAILABLE

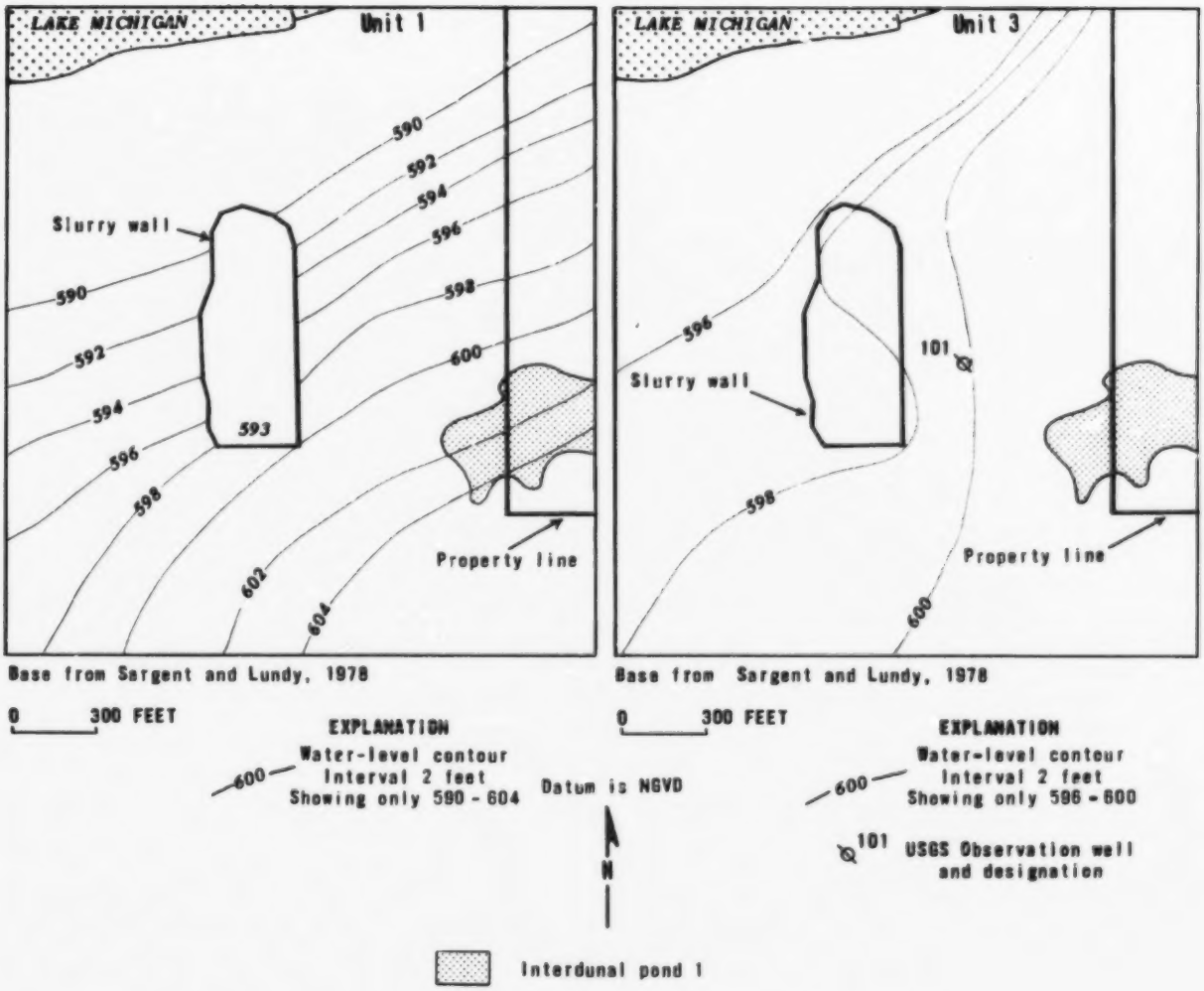


Figure 6.-- Model-simulated water levels in units 1 and 3 near NIPSCO Bailly site for experiment U-7, phase 1 dewatering.

except that the average historical pumpage from the excavation for the prolonged phase 1 dewatering through November 7, 1979 (283 gal/min) was used. The results of experiment U-7 are also shown in table 1.

Model experiments showing the relative importance of slurry-wall hydraulic conductivity and the vertical connection between units 1 and 3 are listed in table 2. The average historical pumpage of 245 gal/min from March 17, 1977, through August 17, 1978, was used in the experiments listed in table 2 to simulate the effects of phase 1 dewatering. Unit 2 under the south one-third of the excavation was simulated as leaky. Except for experiment U-1, the lower of the two values (0.67 ft/d) of vertical hydraulic conductivity used in model experiments S through Z by Meyer and Tucci (1979, p. 73 and table 4) was used in the current study (table 2). Through a series of four experiments (U-2 through U-5), slurry-wall hydraulic conductivity was increased successively by a factor of 10 from its design value 2.8×10^{-4} ft/d. As shown in table 2, for an increase in slurry-wall hydraulic conductivity of 10,000 times over the design value (experiments U-2 through U-5), the difference in water level between unit 3 and unit 1 is not changed substantially. Also, even when the slurry wall is removed entirely (experiment U-8), the simulated difference in water level between units 3 and 1 is still significantly greater than the field-measured differences shown in table 1. Further, results of experiment U-1 in table 2 show that an improved simulation of the difference in water level between units 3 and 1 can be achieved only when the value of the vertical hydraulic conductivity of unit 2 is increased above the value used in experiments U-2 through U-5 and U-8. Experiment U-1 is identical with phase 1 of experiment U of Meyer and Tucci (1979) except that the pumpage from the excavation in experiment U-1 was 245 gal/min rather than 280 gal/min. A better simulation of the difference in water levels between units 3 and 1 is achieved in experiment U-1 despite the simulation of the design value for slurry-wall hydraulic conductivity. The model results shown in table 2, indicate that, although the hydraulic conductivity of the slurry wall does affect the difference in water level between units 3 and 1, the vertical hydraulic conductivity of unit 2 under the south one-third of the excavation is a more sensitive parameter than the hydraulic conductivity of the slurry wall. Also, the conclusion can be made from the experiments shown in table 2 that unit 2 under the south one-third of the excavation is leaky.

On the basis of the preceding analysis of data presented in tables 1 and 2, the authors concluded that the hydrologic conditions simulated in experiments S and U (Meyer and Tucci, 1979, p. 84, table 4) were most representative of the ground-water system in the vicinity of the NIPSCO Bailly site. Therefore, the hydrologic conditions of these experiments were used in all subsequent model analyses of construction dewatering and fly-ash-pond seepage. Because neither of these two experiments simulated field conditions near NIPSCO significantly better than the other, they probably can be used interchangeably for model simulations of water levels near the excavation.

Table 1.--Comparison of measured and simulated water-level declines caused by construction dewatering in USGS well 101 and in the south one-third of NIPSCO excavation: Phase 1 dewatering

Location			In well 101	At excavation			
Type of information			Water-level decline in unit 3 (ft)	Water-level decline in unit 3 (ft)	Water level in unit 1 (ft above NGVD)	Water level in unit 3 (ft above NGVD)	Difference in water level between unit 3 and unit 1 (ft)
Field measurements		8/14-8/16/78	≈2-3	≈11	587.0	[1]590.6	3.6
		9/4-9/5/79	≈2-3	≈11	587.7	590.3	2.6
Meyer and Tucci study[2] (1979)	Slurry wall leaky; confining unit 2 continuous and tight under south one-third of excavation	K	0.6	0.5	592.2	600.5	8.3
		L	.2	.2	580.9	600.9	20.0
		Q	.6	.6	593.1	600.9	7.8
		R	.2	.3	581.6	601.2	19.6
	Slurry wall tight; confining unit 2 discontinuous and leaky under south one-third of excavation	S	3.0	6.3	592.3	594.7	2.4
		U	2.5	5.8	593.3	595.7	2.4
		X	2.9	6.3	570.9	594.8	23.9
		Z	2.3	4.1	572.1	595.8	23.7
Current study	Variation of experiment U[3]	U-7	2.5	5.9	593.2	595.6	2.4

[1]Average of NIPSCO P-1 through P-5.
[2]Assumed average pumping rate: 280 gal/min.
[3]Average historical pumping rate 3-17-77 through 11-7-79: 283 gal/min.

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

Table 2.--Simulated water levels in south one-third of NIPSCO excavation for selected values of slurry-wall hydraulic conductivity: Phase 1 dewatering[1]

Experiment	Slurry-wall hydraulic conductivity (ft/d)	Vertical hydraulic conductivity, unit 2, south one-third of excavation (ft/d)	Water level, unit 1 (ft above NGVD)	Water level, unit 3 (ft above NGVD)	Difference between water levels in units 3 and 1 (ft)
U-2	2.8×10^{-3}	0.67	575.4	596.4	21.0
U-3	2.8×10^{-2}	.67	576.9	596.5	19.6
U-4	2.8×10^{-1}	.67	577.6	596.7	19.1
U-5	2.8	.67	581.7	597.4	15.7
U-8	160.0	.67	592.5	598.3	5.8
U-1	2.8×10^{-4}	6.7	594.3	596.4	2.1

[1]Average historical pumpage of 245 gal/min, 3-17-77 through 8-17-78.

SIMULATION OF REDUCTION OF HYDROSTATIC PRESSURE IN UNIT 3

To evaluate the impact of the revisions in the construction dewatering plan on ground-water levels in the Lakeshore, the authors revised experiments S and U of Meyer and Tucci (1979). Because the model revisions involve changes in the pumping plan only and not in the hydraulic characteristics of the ground-water system, the experiments are hereafter referred to as "revised experiment S" and "revised experiment U." The revisions are (1) extending the duration of phase 1 dewatering through November 7, 1979; (2) lowering the water level to be maintained in the south one-third of the excavation during phase 2 dewatering from 577.7 to 575.7 ft above NGVD; and (3) simulating pumping directly from unit 3 beneath the excavation for reduction of hydrostatic pressure in unit 3.

Phase 1 dewatering in revised experiments S and U was extended by simulating average historical pumpage of 283 gal/min from the excavation from March 17, 1977, through November 7, 1979. Because water-level declines due to construction dewatering are a combination of declines produced by phase 1 and phase 2 dewatering (Meyer and Tucci, 1979, p. 75), the duration of the simulation of phase 1 dewatering could significantly affect final results if phase 1 is not in equilibrium when phase 2 begins. However, the plot of simulated water-level declines at the NIPSCO-NPS boundary east of the excavation for phase 1 dewatering of revised experiment S (fig. 7) indicates that equilibrium is nearly achieved after about 400 days of dewatering. This indicates that phase 1 pumping would cause no significant additional water-level decline after 400 days if the pumping rate remained steady. Therefore, cumulative water-level declines for phases 1 and 2 dewatering would be virtually the same for simulations of phase 2 dewatering beginning at any time after about the 400th day of phase 1. Thus, in the formulation of revised pumping plans for model simulations, the duration of phase 1 dewatering is no longer significant because phase 1 dewatering already exceeds more than 1,000 days. This conclusion is valid if the pumping rate from the excavation remains steady.

Pumping directly from unit 3 for reduction of hydrostatic pressure in that unit was simulated in revised experiments S and U by assigning a constant head of 583.7 ft above NGVD to unit 3 at the model node representing the south one-third of the excavation and then holding it constant throughout the 18-month duration of phase 2 dewatering. Selection of this water level to represent the average requirement for reduction in hydrostatic pressure in unit 3 under the excavation was based on data presented in the report by Sargent and Lundy (1979).

Simulated water-level declines in units 1 and 3 for revised experiment U after 18 months of phase 2 dewatering are shown in figures 8 and 9, respectively. As in experiments S and U of Meyer and Tucci (1979), the authors assumed that seepage from the fly-ash ponds continued at the model-simulated rate of 1.96 Mgal/d throughout construction dewatering for revised experiment U. Thus, the simulated water-level declines shown in figures 8 and 9 can be compared directly with simulated declines shown in figures 35 and 37 of Meyer and Tucci (1979), respectively. Simulated water-level declines in unit 1 for

BEST DOCUMENT AVAILABLE

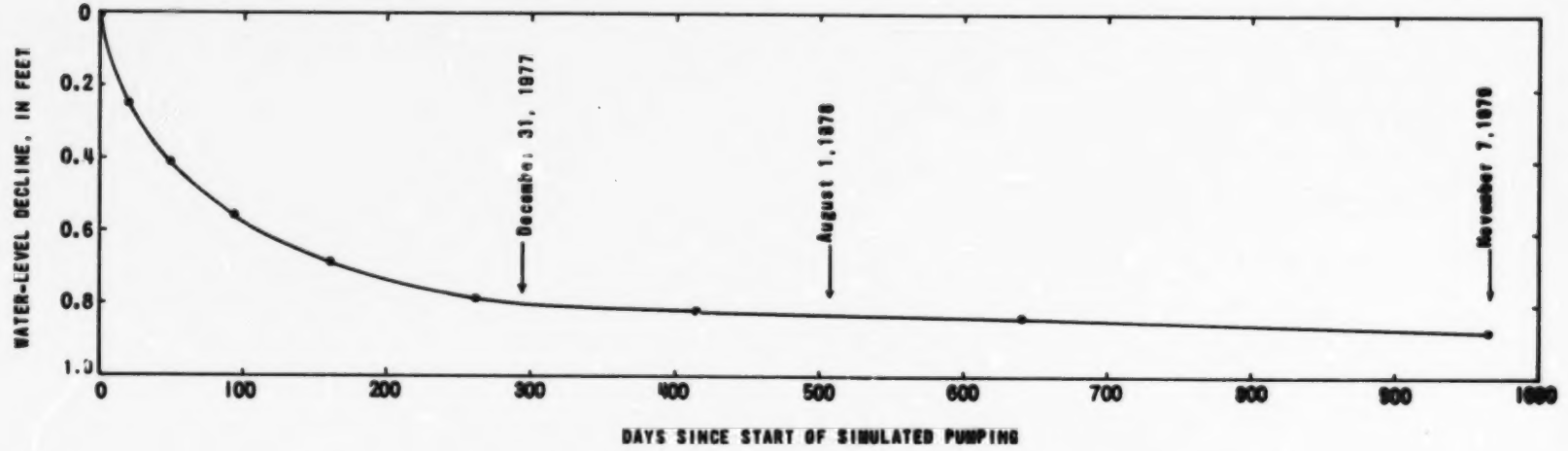


Figure 7.-- Model simulated water-level declines at the NIPSCO-NPS boundary east of the excavation, for revised experiment S, phase I dewatering.

revised experiment U are only slightly greater than those produced by experiment U of Meyer and Tucci (1979). This near agreement indicates that simulation of an extended phase 1 dewatering, a lower maintenance of the water level in the excavation for phase 2 dewatering, and direct pumping from unit 3 produce an estimated impact on water levels within the Lakeshore that differs little from those estimated by Meyer and Tucci (1979). The model-calculated rate of pumping from the excavation at the end of revised experiment U was 819 gal/min of which 816 gal/min is from unit 3 and 3 gal/min from unit 1. The total rate compares fairly closely with the 710 gal/min for experiment U of Meyer and Tucci (1979, table 4).

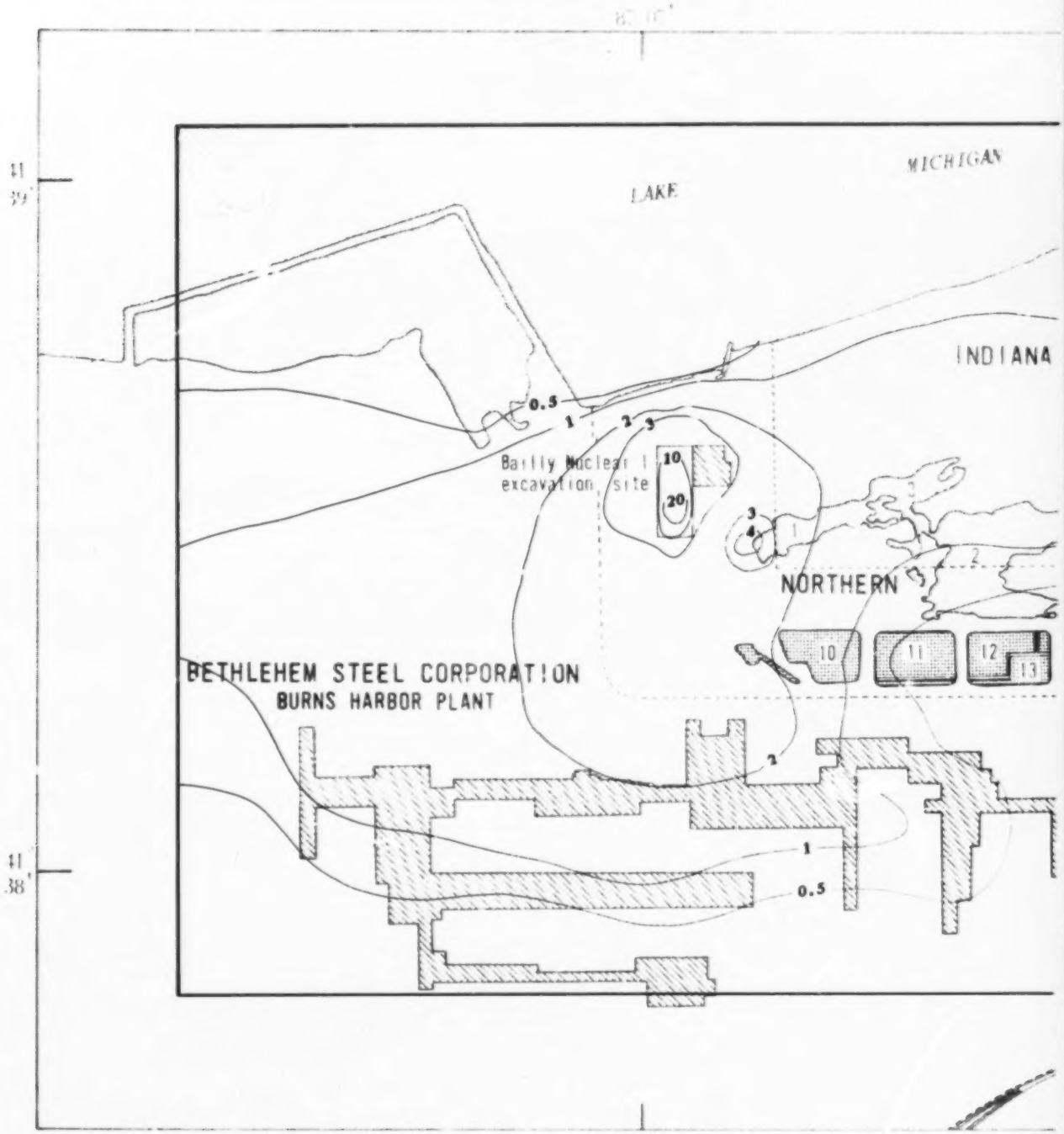
SIMULATION OF SIMULTANEOUS CONSTRUCTION DEWATERING AND DECLINE OF SEEPAGE MOUND

The NPS obtained an agreement with NIPSCO for sealing the fly-ash ponds so that ground-water levels within the Lakeshore affected by seepage from the ponds may return to normal. The NPS wants to restore and preserve natural water levels in the Lakeshore.

Pre-fly-ash pond water levels within the Lakeshore were never documented, but they can be estimated by model simulation. Meyer and Tucci (1979, p. 59-68, experiment A) simulated the pre-fly-ash pond water levels within the Lakeshore by terminating the fly-ash pond seepage in the model. Model-simulated water-level declines in unit 1 for simulated termination of fly-ash-pond seepage are shown in figure 27 of Meyer and Tucci (1979, p. 64-65). During the simulation, pumping rates from wells at Bethlehem Steel Corp. were simulated at the same rate as for model calibration. (See Meyer and Tucci, 1979, p. 49.) The simulated pre-fly-ash pond water levels in unit 1 are shown in figure 10. According to the simulation, these water levels would have been present in unit 1, on October 26, 1976 (the calibration period of the model) if there had been no seepage from the fly-ash ponds. For determining the magnitude of the impact of dewatering due to pumping from NIPSCO's excavation on water levels naturally present in unit 1, these simulated pre-fly-ash pond water levels are hereafter referred to as "reference water levels."

Results of simulations of simultaneous construction dewatering and seepage-mound decline after sealing of the fly-ash ponds are presented as deviations from "reference water levels." These deviations were calculated by subtracting the "reference water levels" from final model-simulated water levels at each model node. The deviations were then contoured. The results of revised experiment U with simulated decline of the seepage mound are shown in figure 11. In this simulation, phase 2 dewatering (with simulation of reduction in hydrostatic pressure in unit 3) and decline of the seepage mound began simultaneously and continued for 18 months. In figure 11, negative contours represent simulated water levels that are below "reference water levels," and positive contours represent simulated water levels that are

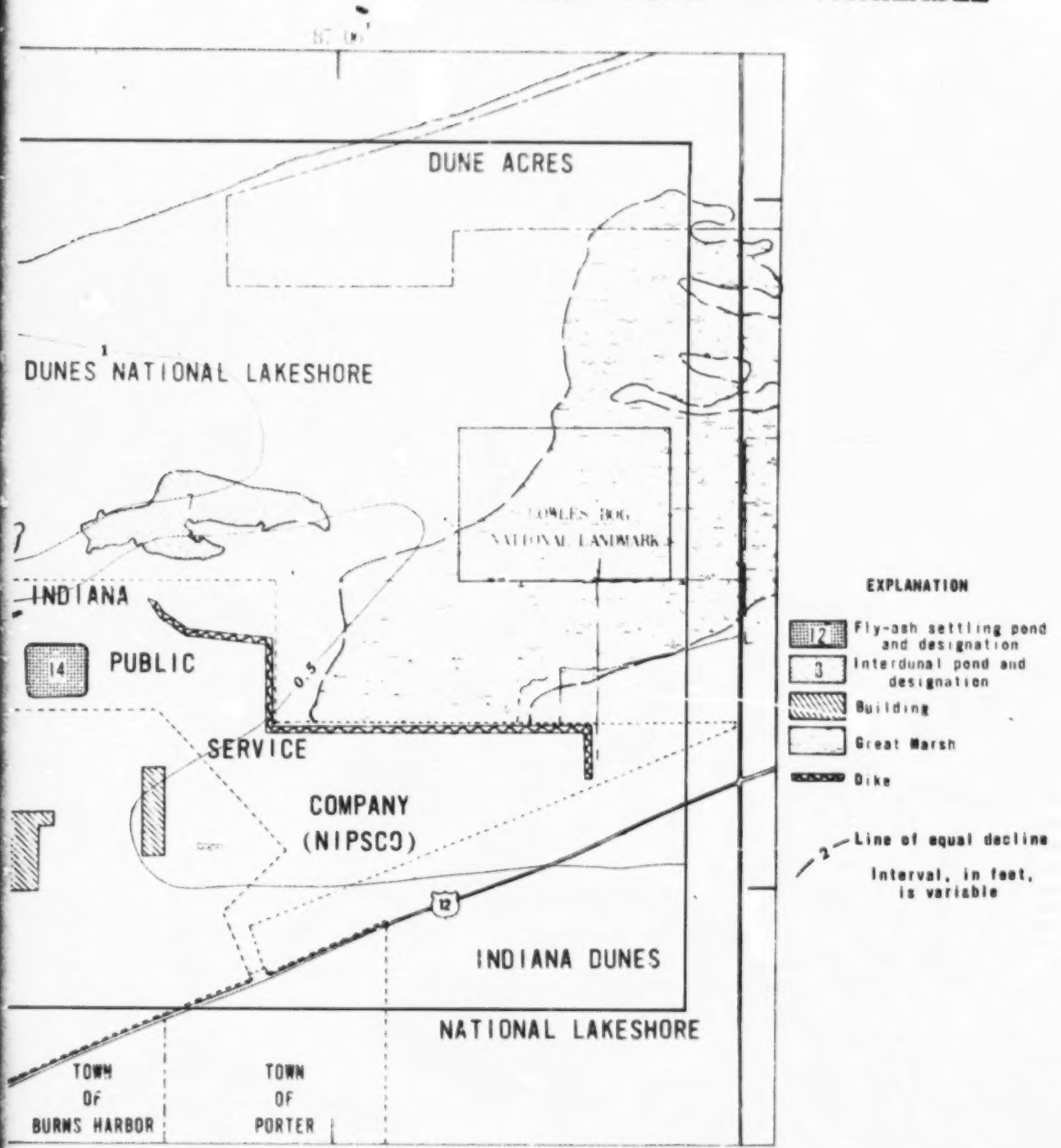
BEST DOCUMENT AVAILABLE



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968, 1973 NIPSCO Map No. MS-150, by Sargent and Lundy, and National Park Service, November 1978

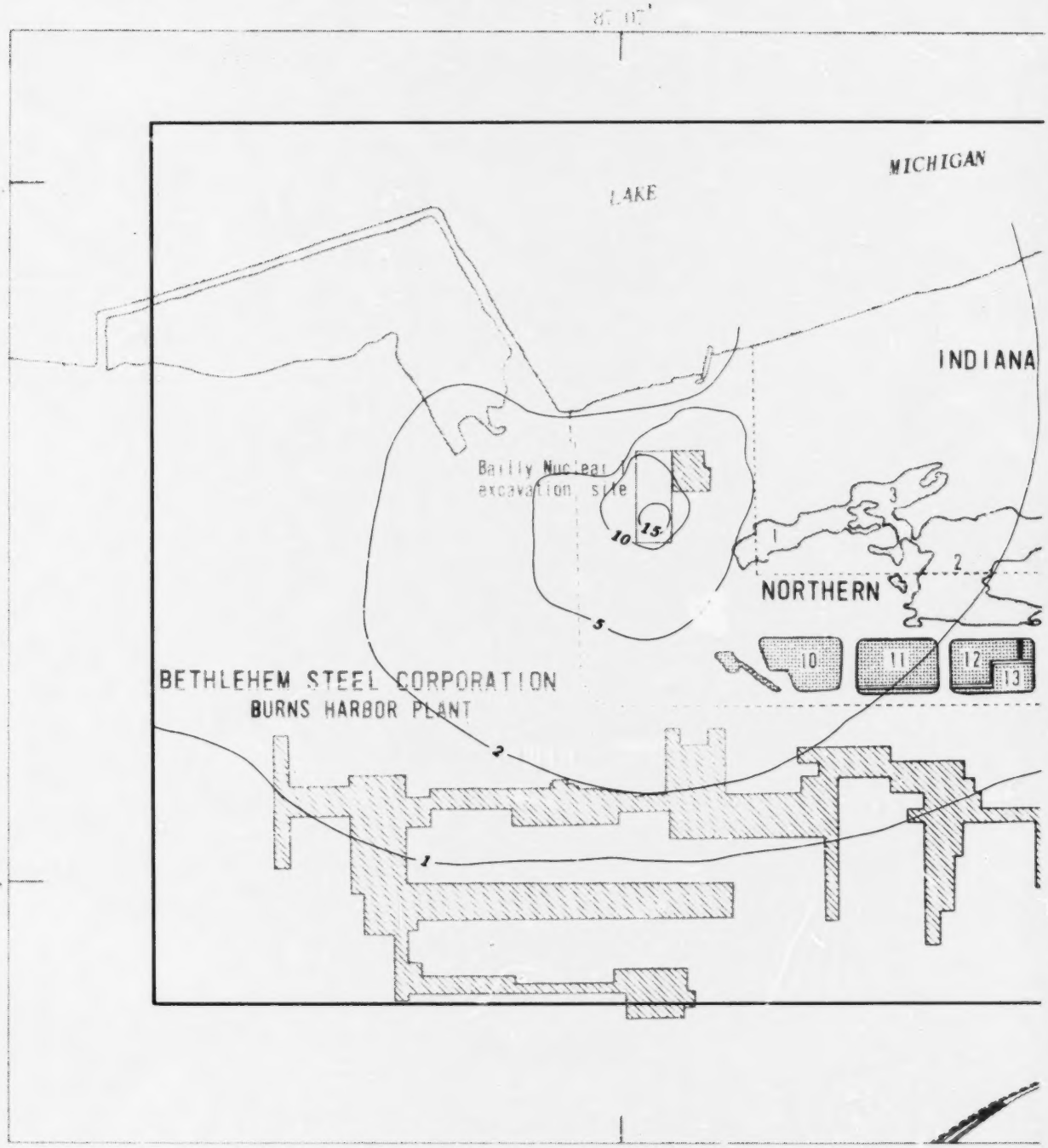
Figure 8.-- Model-simulated water-level declines in unit 1 after 18 months of

BEST DOCUMENT AVAILABLE



phase 2 construction dewatering (revised experiment U).

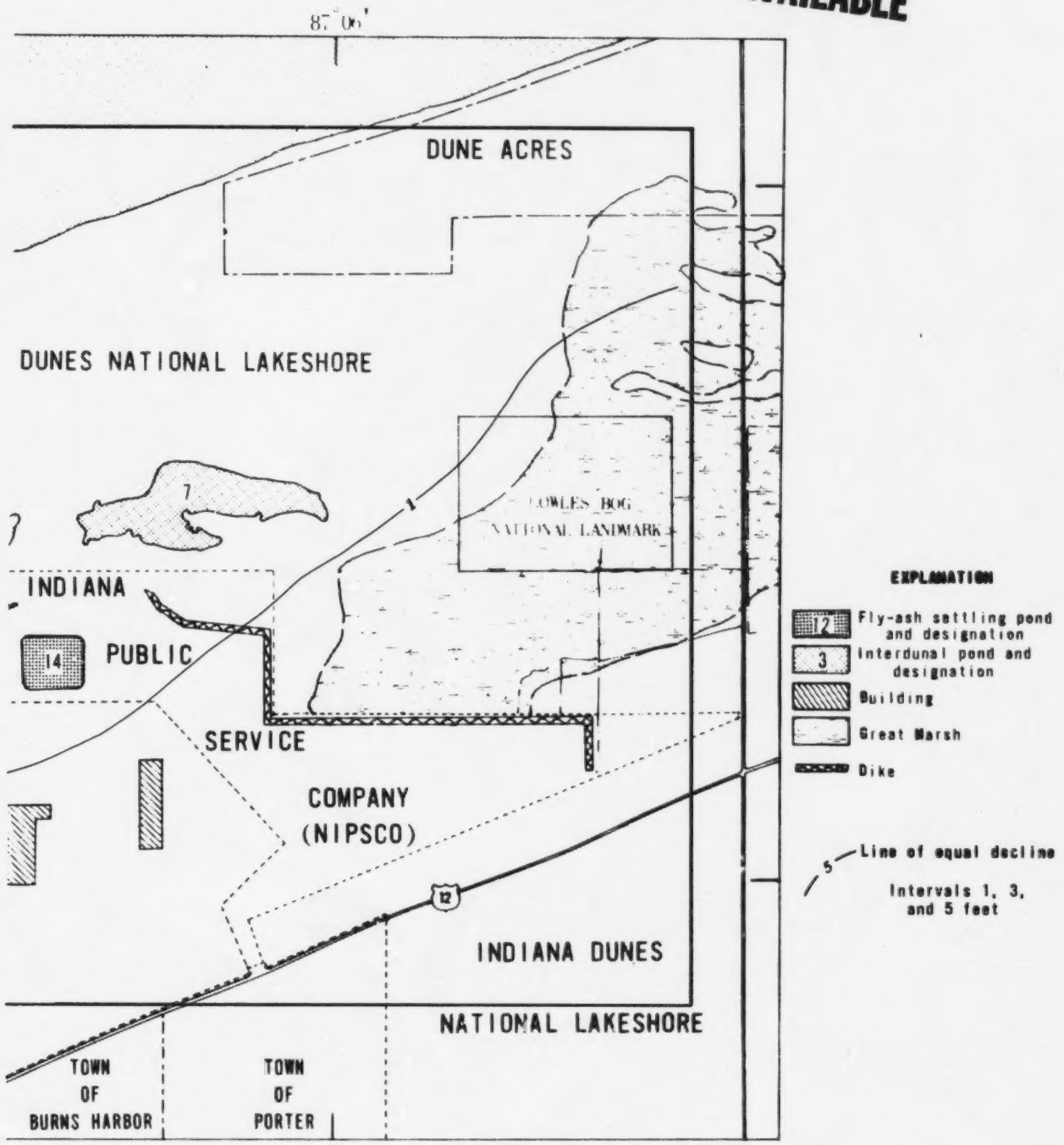
BEST DOCUMENT AVAILABLE



Base from U.S. Geological Survey, Dune Acres 1:24 000, 1968, 1973 NIPSCO Map No. MS-150, by Sargent and Lundy, and National Park Service, November 1978

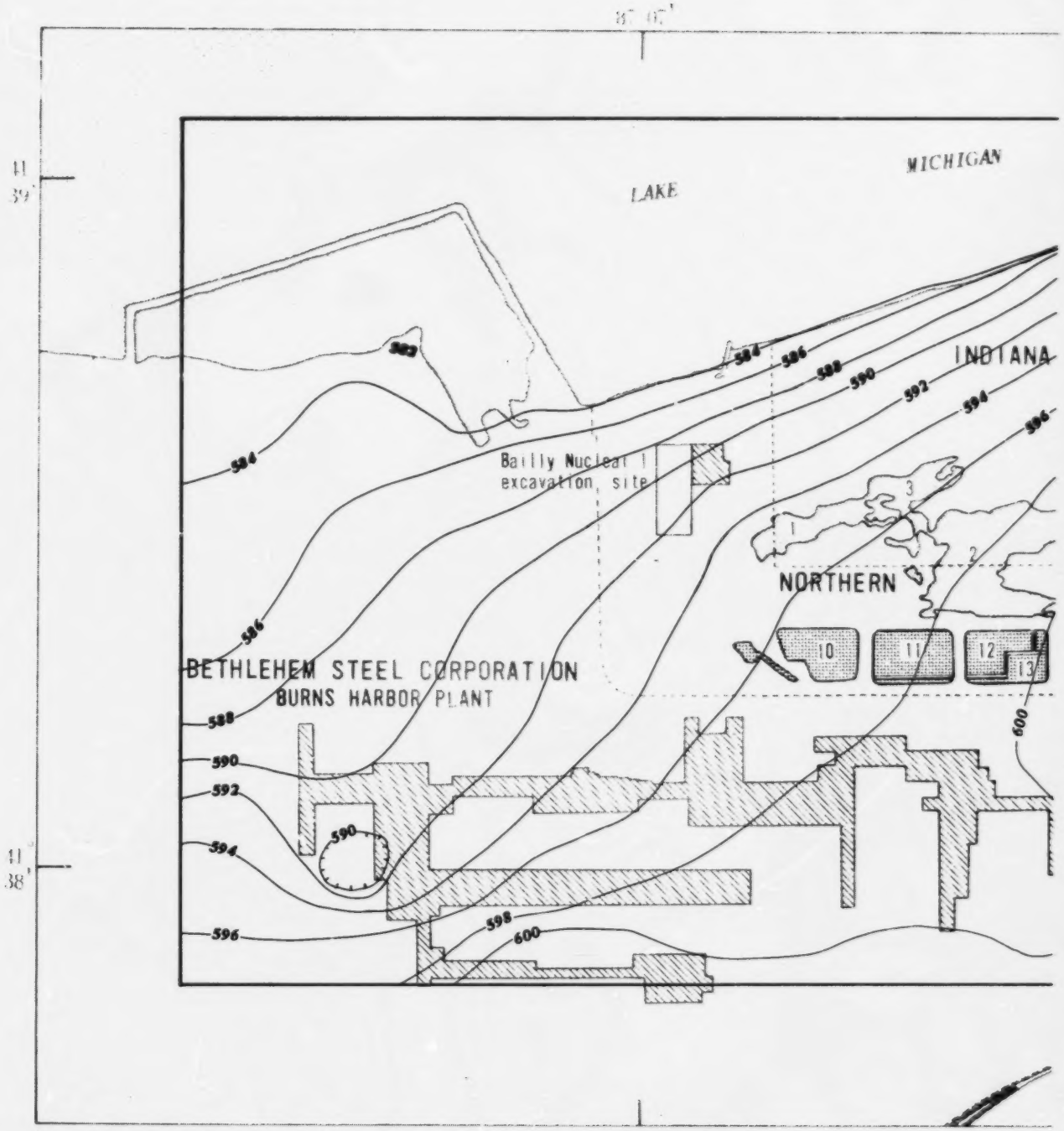
Figure 9.-- Model-simulated water-level declines in unit 3 after 18 months of

BEST DOCUMENT AVAILABLE



phase 2 construction dewatering (revised experiment U).

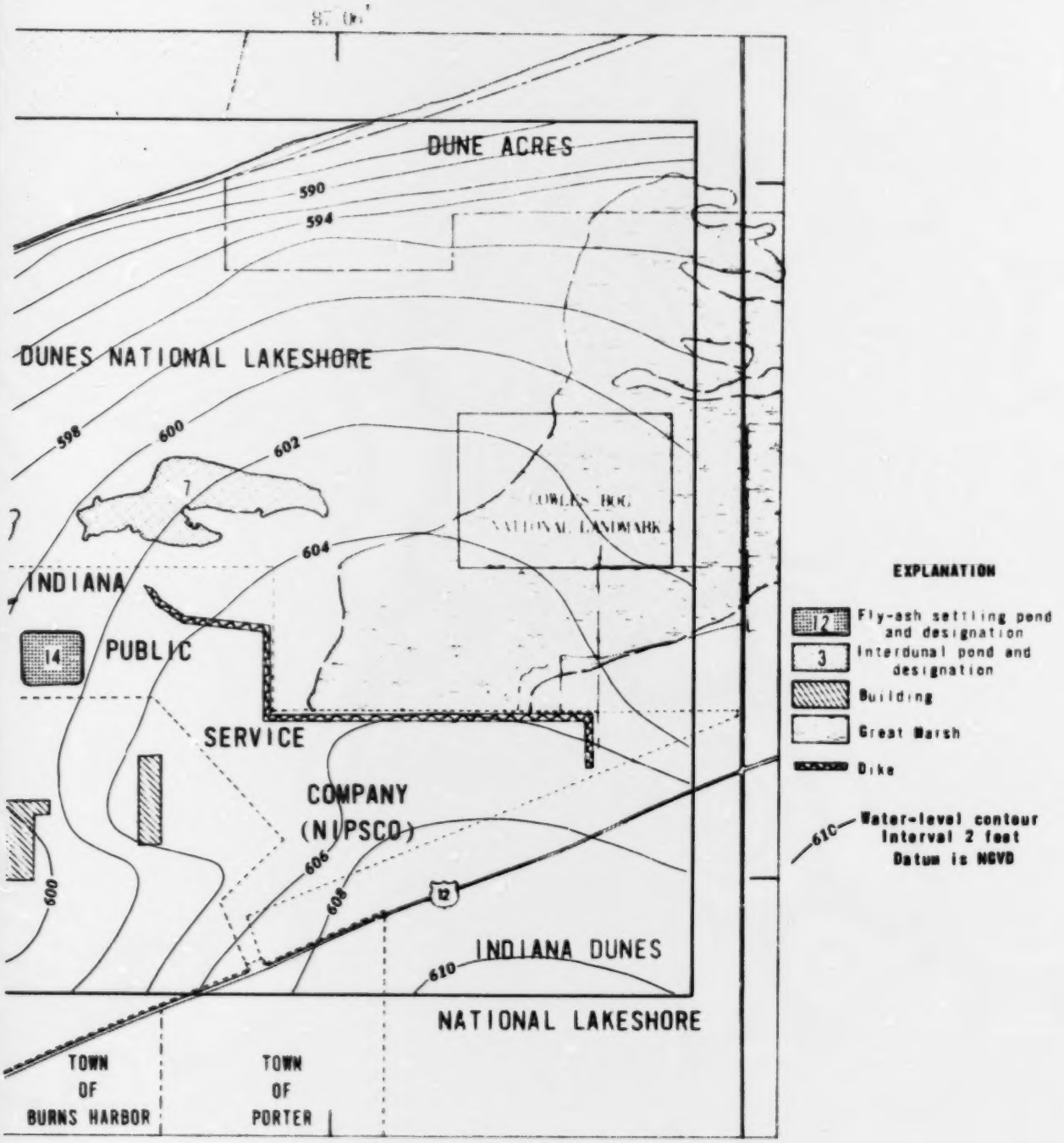
BEST DOCUMENT AVAILABLE



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968; 1973 NIPSCO Map No. MS-150, by Sargent and Lundy, and National Park Service, November 1978

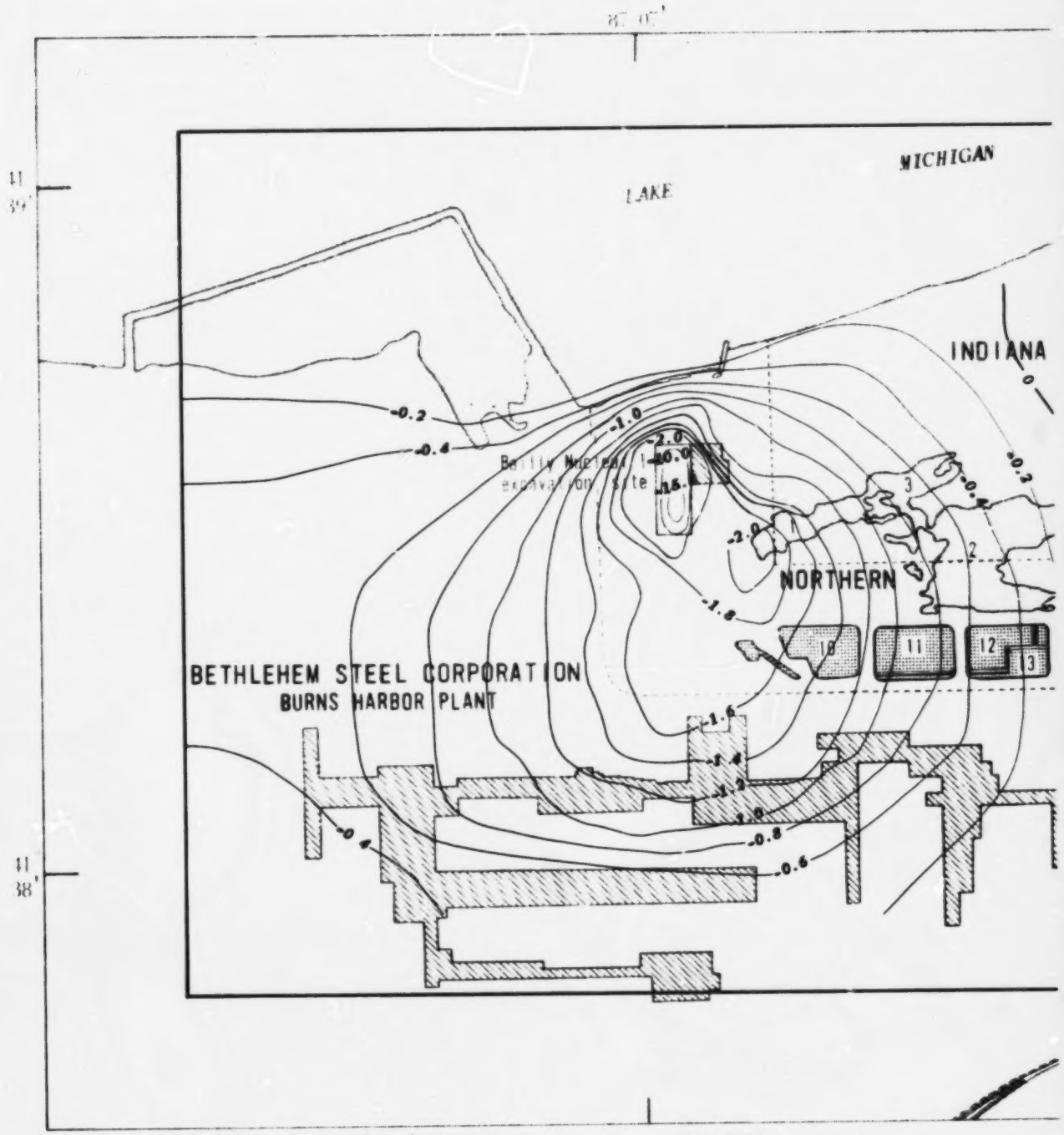
Figure 10.-- Model-simulated water levels in unit 1 for simulated termination of

BEST DOCUMENT AVAILABLE



fly-ash-pond seepage (simulated by Meyer and Tucci, 1979).

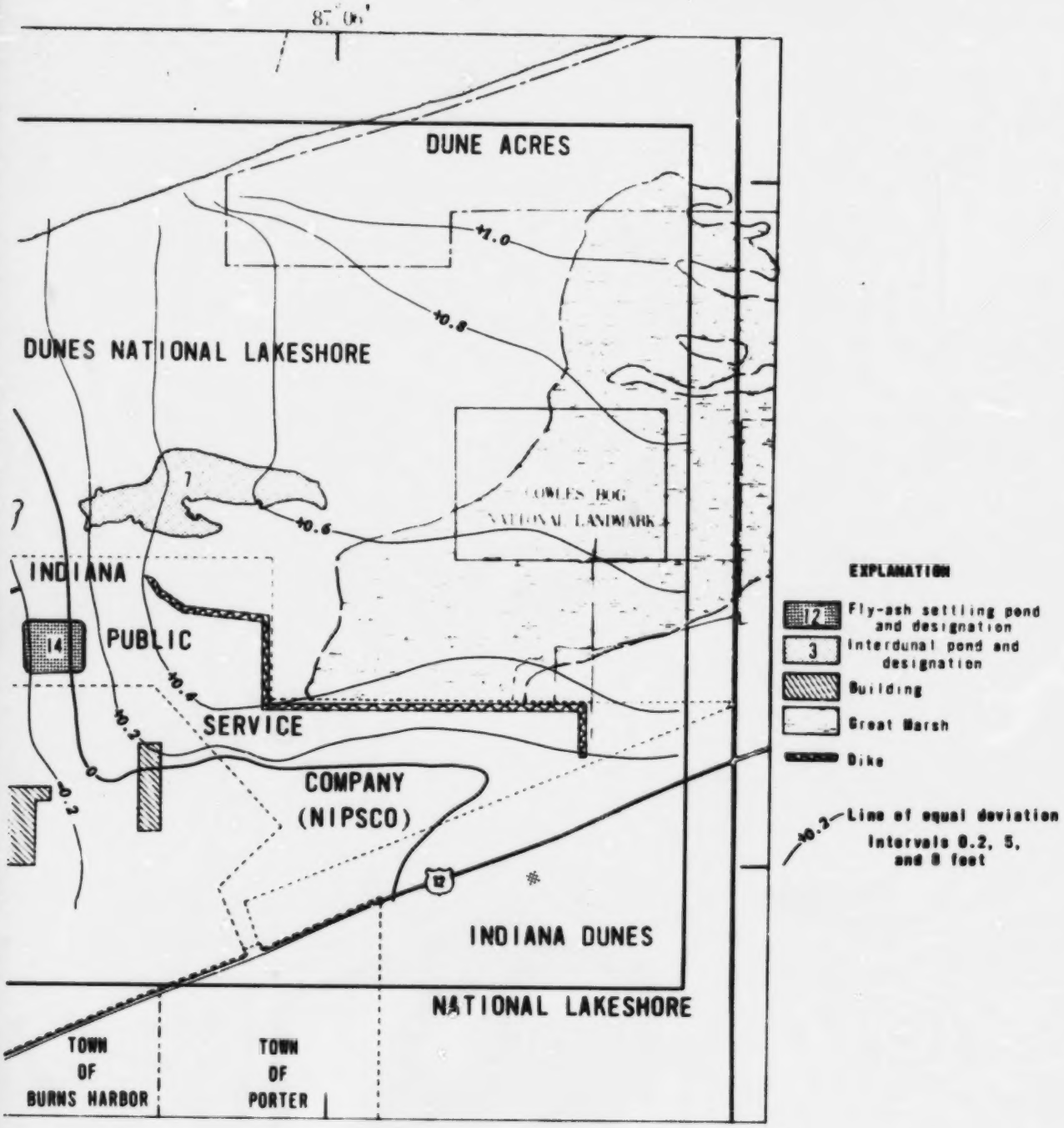
BEST DOCUMENT AVAILABLE



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968. 1973 NIPSCO Map No. MS-150, by Sargent and Lundy, and National Park Service, November 1978

Figure 11.-- Deviation of model-simulated water levels in unit 1 from ''reference water levels'' after

BEST DOCUMENT AVAILABLE



18 months of phase 2 construction dewatering (revised experiment U) and decline of seepage mound.

above "reference water levels." Within the Lakeshore is an area underlying ponds 1, 2, and 3 where, according to the simulation, water levels in unit 1 are as much as 1.8 ft below the "reference water levels" because of construction dewatering. The results of the simulation demonstrate the need for mitigation and provide estimates of the magnitude of water-level deficiencies (declines below "reference water levels") that must be made up by the mitigation program in order to maintain water levels at the "reference water levels." In the east half of the study area is a broad area within the Lakeshore where, because the seepage mound has not completely dissipated after 18 months, simulated water levels in unit 1 are still above "reference water levels." Meyer and Tucci (1979, p. 68 and fig. 29) indicated that most of the seepage mound would dissipate in 2 yr and that the mound would stabilize in about 9 yr. The model-calculated rate of pumping from the excavation at the end of the simulation period, which produced the results shown in figure 11 is 560 gal/min. All but 3 gal/min comes from unit 3. This rate of pumping is lower than the rates that produced the results shown in figures 8 and 9 because of the dissipation of much of the seepage mound from the area of the excavation.

SIMULATION OF PROPOSED MITIGATION

NIPSCO has agreed to mitigate the effects of construction dewatering on ground-water levels within the Lakeshore by recharging water into unit 1 between the excavation and the NIPSCO-NPS boundary. The trickling-filter recharge system to be used in the mitigation program is described by Sargent and Lundy (1978, p. 12-14, exhibits 18 and 19). The mitigation program was simulated in the model by inputting water to the three model nodes most closely corresponding to the location of the trickling-filter recharge system. The three node blocks are in column 14, rows 12-14 of the model grid shown in Meyer and Tucci (1979, p. 54, fig. 24). In this grid, the block in the upper left-hand corner is column 2, row 2. The column numbers increase to the right from this block through column 39, and the row numbers increase down through row 25. The simulations assume that all the water from the trickling-filter recharge system reaches the ground-water system. The model cannot be used to estimate the efficiency of the recharge system.

Mitigation was simulated for two different recharge rates and the conditions of revised experiment U. Continuous input of recharge water, phase 2 dewatering, and decline of the seepage mound all began simultaneously at the start of both simulations. Both simulations were run for 18 months. The results of these two simulations, one with mitigation of 200 gal/min and one of 400 gal/min, are shown as deviations of model-simulated water levels from "reference water levels" in figures 12 and 13, respectively. According to Sargent and Lundy (1978), 400 gal/min is the maximum estimated capacity of the trickling-filter recharge system.

Figure 12 indicates that much of the simulated water-level deficiency shown in figure 11 has been made up by the mitigation system. However, a small area of water-level deficiency is present in the southwest corner of the Lakeshore beneath pond 1. Here, water levels are still as much as 0.4 ft below "reference water levels." However, figure 13 indicates that when 400 gal/min of recharge water is used, all the water-level deficiency within the Lakeshore is made up. In both simulations, a ground-water mound is produced by the mitigation. With 400 gal/min mitigation, the mound is large enough so that it underlies a part of the Lakeshore east of the property line (fig. 13). Model-calculated rates of pumping from the excavation at the end of the simulation period, which produced the results shown in figures 12 and 13, were 609 and 657 gal/min, respectively. Whether the actual ground-water system will behave in the same manner as the model simulation depends on how well the model simulates the physical properties of the ground-water system and the artificial recharge of water for mitigation. Therefore, these model simulations should not be viewed as precise predictions of what will occur in the field, but rather as an estimation of what may occur.

DISCUSSION OF AND SIMULATIONS RELATED TO THE LATERAL VARIATION OF THE HYDRAULIC CHARACTERISTICS OF THE CONFINING UNIT AT COWLES BOG

During the summer of 1979, the USGS installed approximately 40 small-diameter observation wells in the Great Marsh area of the Lakeshore from near the NIPSCO Bailly site northeastward to Michigan City. These hand-driven wells were installed so that the 3-ft well screens just penetrated the top of the sand in unit 1 immediately underlying the organic layer and water in the marsh. Seven of these wells were installed in the marsh area in the vicinity of Cowles Bog west of Mineral Springs Road. Water levels in two of the wells were above the level of the standing water in the marsh. Correlating the water levels in these two wells with water levels in other wells penetrating unit 1 suggested that there is a ground-water mound in unit 1 at Cowles Bog.

In February 1980, the USGS and NPS installed 9 additional wells in unit 1 within Cowles Bog to verify the mound and to define its extent. Depth of the 16 Great Marsh wells in the marsh area west of Mineral Springs Road ranges from about 7 to 20 ft and averages about 13 ft. Water levels from these and other USGS observation wells near Cowles Bog in unit 1, measured on February 25-29, 1980, are contoured in figure 14. The dimensions of the ground-water mound defined by the 606-ft contour are roughly 1,600 ft east-west and 400 ft north-south. Water levels in unit 1 within the mound are as much as 5 ft higher than in unit 1 beneath the surrounding marsh area. The mound apparently coincides with a topographic rise that is also as much as 5 ft higher than the land or open-water surface in the surrounding marsh.

The ground-water mound in unit 1 at Cowles Bog is probably due to a thinning or absence of the confining unit (unit 2) beneath the center of the bog that normally separates units 1 and 3, or a greater value of the vertical hydraulic conductivity of unit 2 beneath the center of the bog than elsewhere,

BEST DOCUMENT AVAILABLE

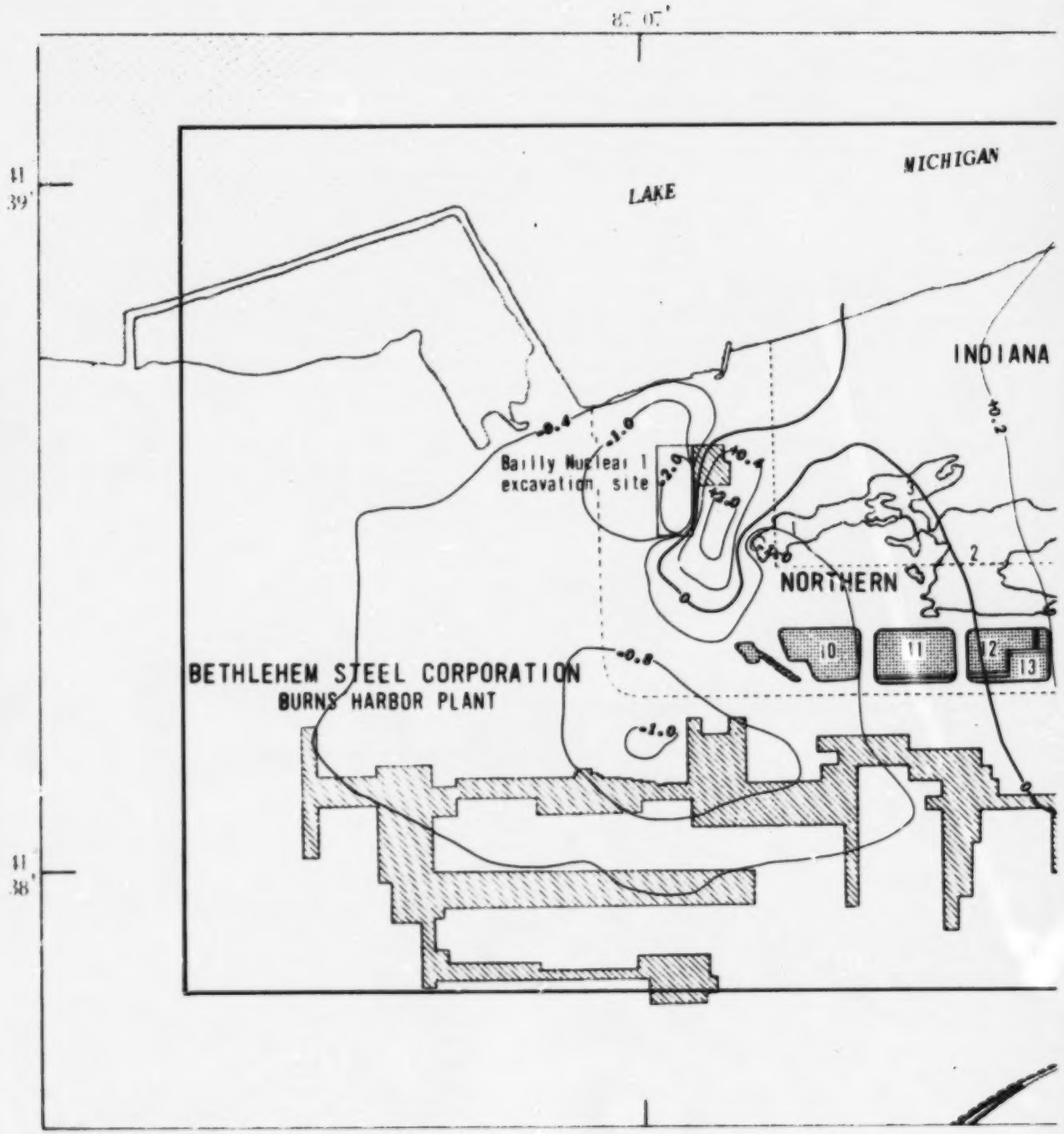
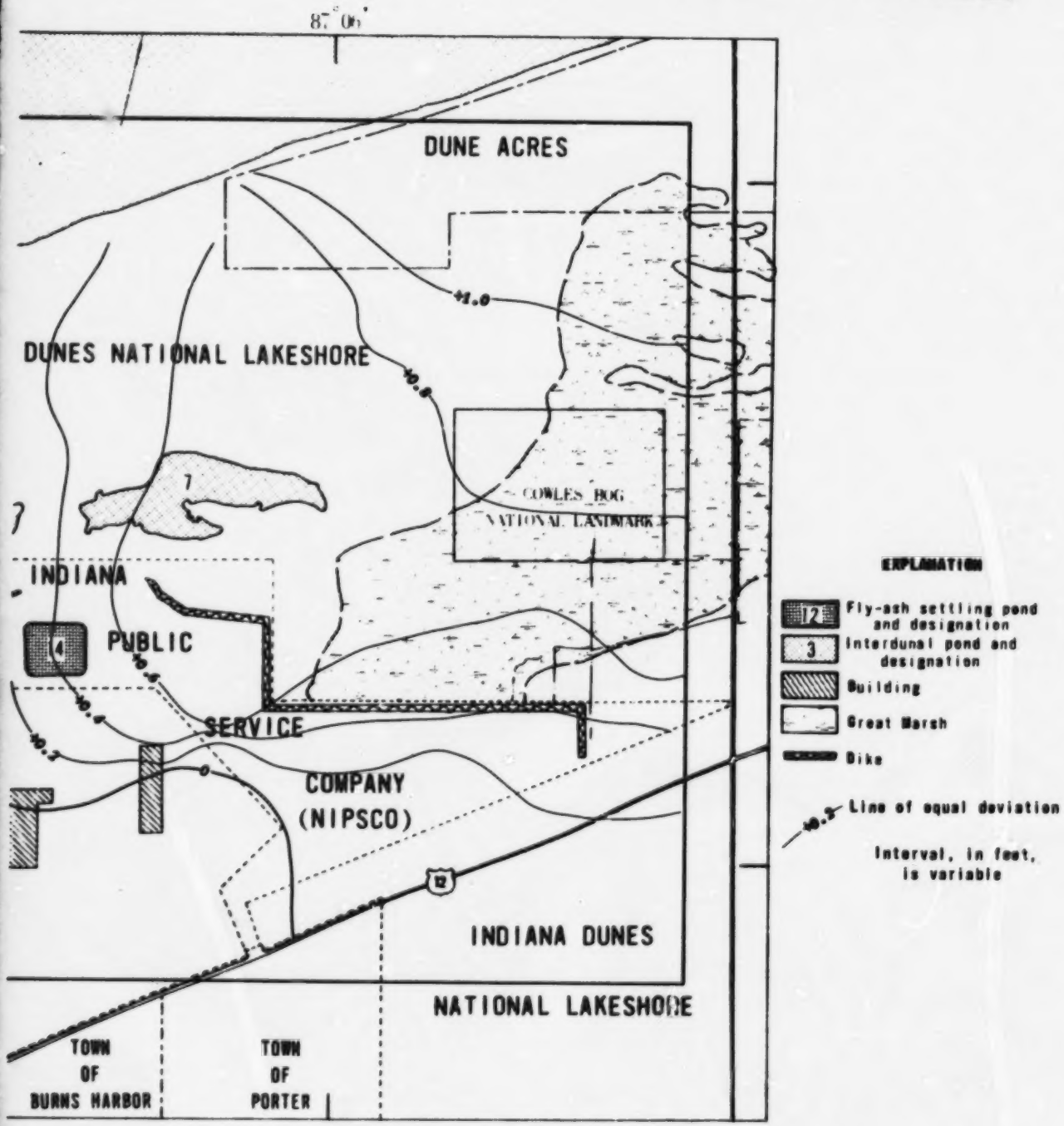
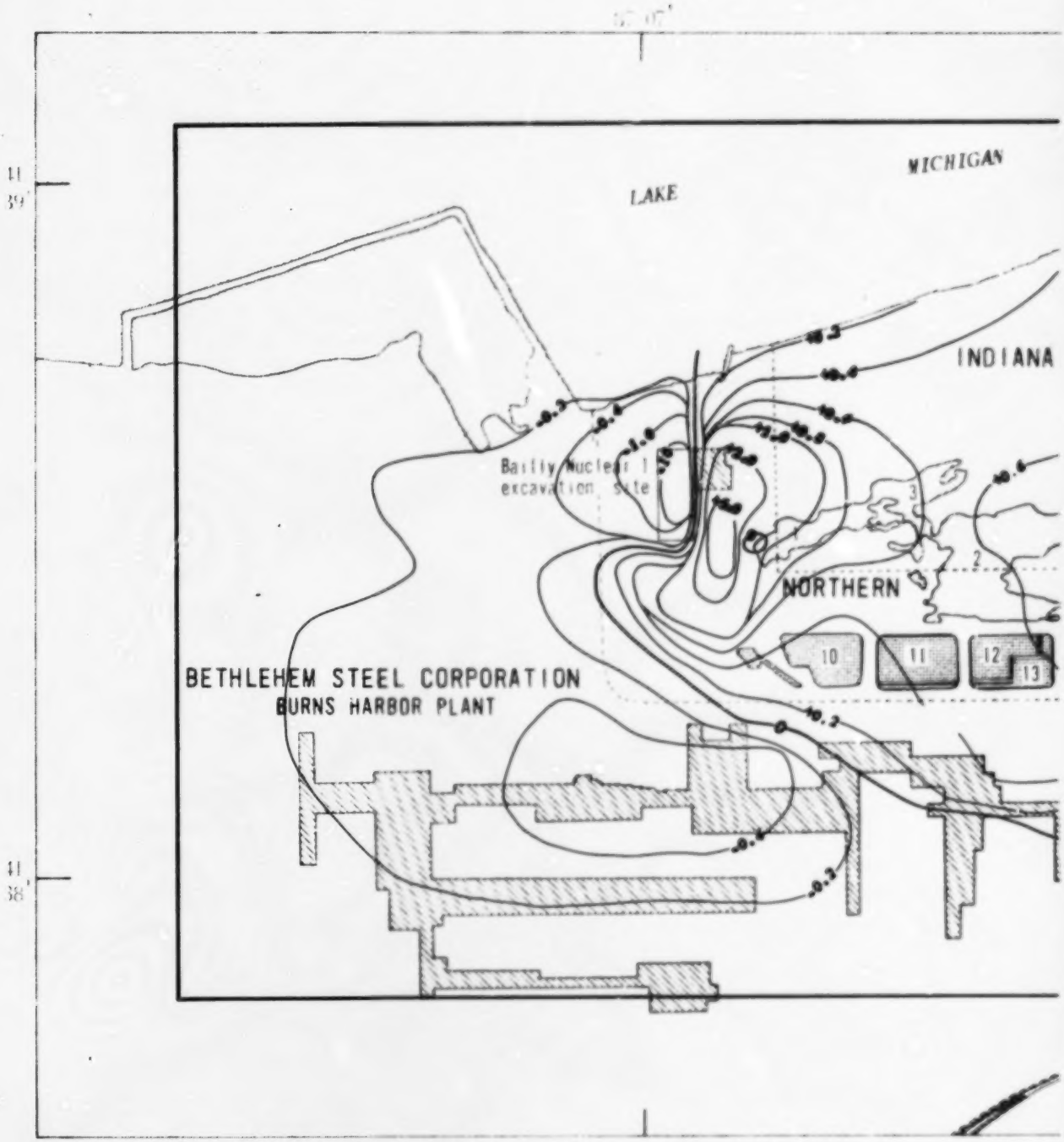


Figure 12.-- Deviation of model-simulated water levels in unit 1 from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment U), decline of seepage mound, and mitigation at 200 gal/min.

BEST DOCUMENT AVAILABLE



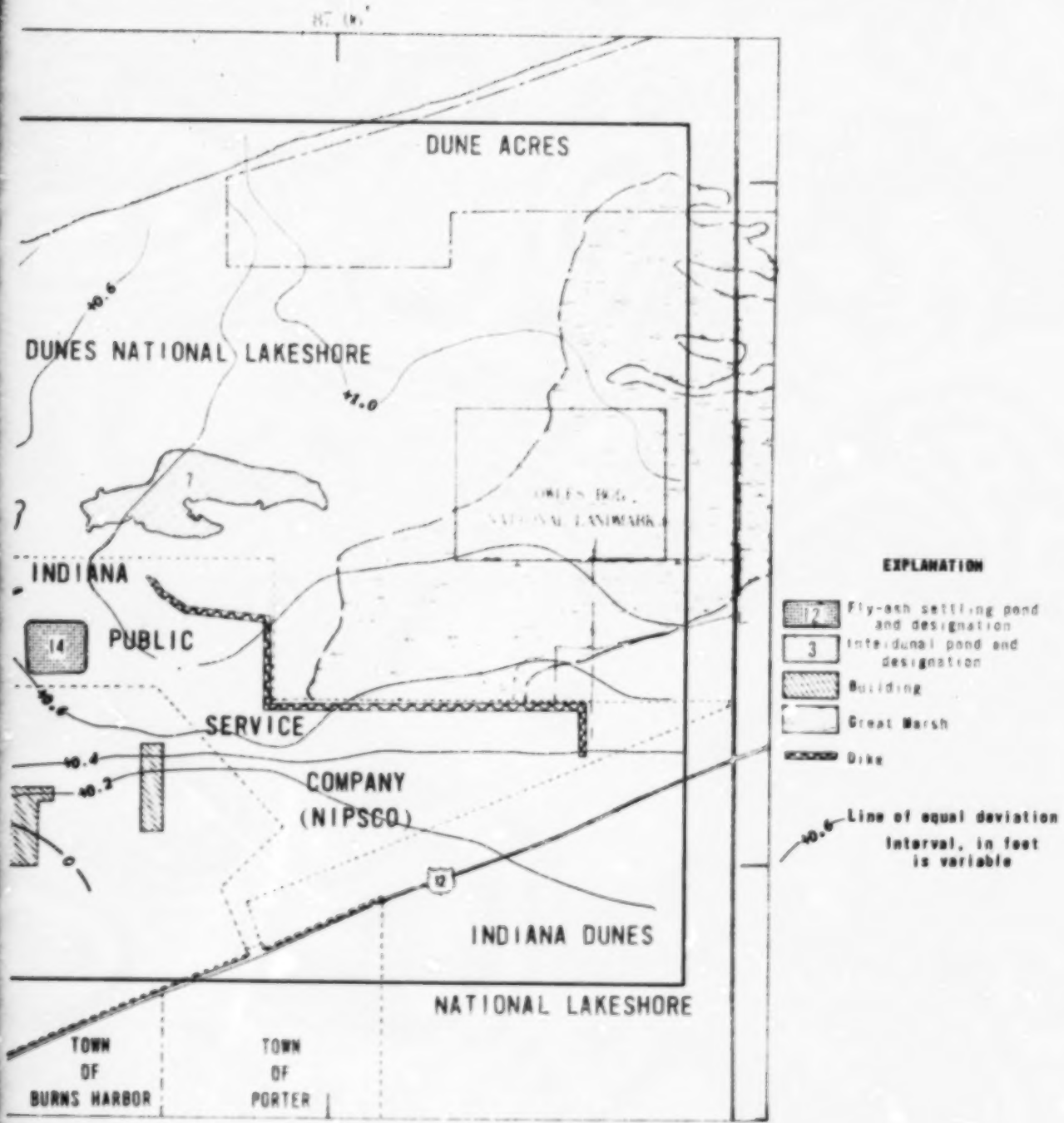
BEST DOCUMENT AVAILABLE



Base from U.S. Geological Survey, Dune Acres 1:24,000, 1968. 1973 NIPSCO Map No. MS-150, by Sargent and Lundy, and National Park Service, November 1978

Figure 13.-- Deviation of model-simulated water levels in unit 1 from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment U), decline of seepage mound, and mitigation at 400 gal/min.

BEST DOCUMENT AVAILABLE



BEST DOCUMENT AVAILABLE

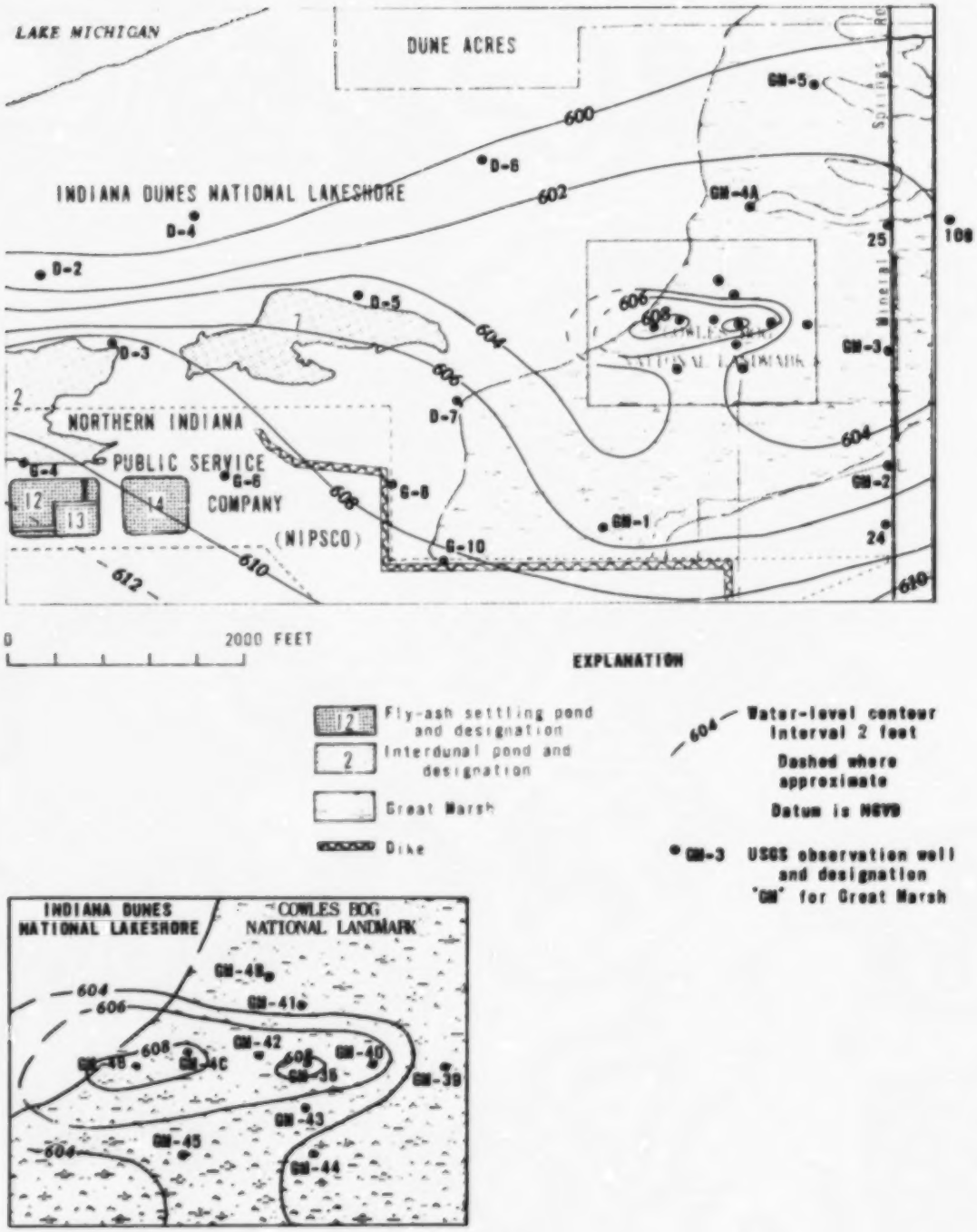


Figure 14. -- Water levels in unit 1 near Cowles Bog, February 25-28, 1980.

or a combination of both factors. The variation in one or both of the characteristics of the confining unit, hereafter termed a "discontinuity," results in a better connection between the two aquifers (units 1 and 3) than elsewhere. Upward flow from unit 3 to unit 1 through the confining unit (unit 2) is well documented in the study area and throughout the Lakeshore. For example, upward flow is evident at well 108, about 2,000 ft northeast of Cowles Bog and east of Mineral Springs Road (fig. 14), where the water level in unit 3 was about 2.2 ft higher than the level in unit 1 in February 1980. The better hydraulic connection beneath Cowles Bog apparently allows greater quantities of ground water to discharge upward from unit 3 into unit 1 through the "discontinuity" than where the confining unit is present and thus to produce the mound in unit 1 at the bog. Other documented "discontinuities" in the confining unit include one at the west end of pond 1 and another in the south part of the study area (Meyer and Tucci, 1979, fig. 7). There also may be a "discontinuity" under the south part of the excavation.

Although the hypothesis of the "discontinuity" in the confining unit at Cowles Bog has not been proven with direct evidence such as test borings and corings, the mound in unit 1 indirectly supports it. The USGS and NPS will continue to gather data that will expand and refine the present understanding of the hydrology of Cowles Bog. For now, the hypothesis that a "discontinuity" exists in the confining unit underlying Cowles Bog is assumed, and the model simulations that follow incorporate this "discontinuity."

The hydraulic conditions used in experiment S of Meyer and Tucci (1979, table 4) were used in the simulation of the "discontinuity" in the confining unit at Cowles Bog. The results of experiments S and U were similar (as were the results of revised experiments S and U). However, the lower vertical hydraulic conductivity of the confining unit used in experiments S and revised S produced a better simulation of the observed difference between water levels in units 1 and 3 in Cowles Bog than experiments U and revised U. The node block "row 11, column 38" of the model grid was used to simulate the "discontinuity" in the confining unit. (See Meyer and Tucci, 1979, fig. 24.) A vertical hydraulic conductivity of the sand aquifer units was used to simulate the vertical hydraulic connection of the confining unit between units 1 and 3 at that location.

Because Cowles Bog is close to the edge of the model area, the effect of the model boundary on simulations of seepage-mound decline and construction dewatering must be considered. Simulation of a constant-flux boundary along the east edge of the model would tend to maximize water-level changes attributed to seepage-mound decline and construction dewatering by maintaining constant flow in or out of the model boundary. Simulation of a constant-head boundary would tend to minimize water-level changes by supplying unlimited flow across the model boundary, which maintains constant water levels at the boundary. Meyer and Tucci (1979, experiments A and B, p. 68) discussed the effect of these two boundary conditions and indicated that the water-level declines in the interior of the modeled area for units 1 and 3 were nearly identical for both boundary conditions. However, at the east boundary of the model, model-simulated water-level declines in unit 1, when a constant-flux boundary were used, was about 1.6 ft for simulation of termination of fly-ash-pond seepage (Meyer and Tucci, 1979). When a constant-head boundary was used, water levels at the east boundary of the model did not decline. This

difference in water-level decline at the east boundary of the model for simulations of the two boundary conditions was not critical in Meyer and Tucci's study because the focus of their study was the area near the west boundary between NIPSCO and the Lakeshore. However, the magnitude of water-level declines due to termination of fly-ash-pond seepage along the east boundary of the model is critical in the consideration of impact of seepage-mound decline and construction dewatering on the aquifer system at Cowles Bog. Selection of the model boundary could cause simulated "reference water levels" to differ by as much as 1.4 ft. (See table 3, item 6.). Thus, for all model simulations involving the "discontinuity" in the confining unit at Cowles Bog, both constant-head and constant-flux boundary conditions were used in both units 1 and 3 along the east edge of the model. The two boundary conditions result in maximum and minimum effects on water levels at Cowles Bog caused by seepage-mound decline and construction dewatering. Although the storage properties of unit 1 were considered in the simulations, the storage properties of the Great Marsh were not. Standing water in the marsh and water in the organic mat could moderate water-level declines.

Table 3 is a summary of the results of model simulations in which the "discontinuity" at Cowles Bog was simulated (items 5-9) as well as results of previous simulations in which the discontinuity was not simulated (items 1-4). In the table, model node "11, 38" (row 11, column 38) is the location where the "discontinuity" was simulated. For items 1-4, only a single value is given because these experiments were simulated with a constant-flux boundary along the east edge of the model. However, for items 5-9, maximum and minimum effects derived from the simulation of a constant-flux and a constant-head boundary along the east edge of the model are given.

Comparison of item 5 with item 1 of table 3 indicates that when the "discontinuity" in the confining unit at Cowles Bog is simulated, the water levels in units 1 and 3 equilibrate to a level in between the former water levels of units 1 and 3 but closer to the former water level in unit 3. Water-level declines are greater in unit 1 for the simulations in which the "discontinuity" was simulated than for the comparable simulation in which the "discontinuity" was not simulated (items 2-4). Therefore, one can conclude that water-level declines in unit 1 at Cowles Bog would intensify because of the "discontinuity" in the confining unit.

Maximum and minimum simulated water-level declines in unit 1 due to seepage-mound decline are shown in figures 15 and 16, respectively. These simulations are repeats of Meyer and Tucci's (1979) experiments A and B, except that the "discontinuity" in the confining unit at Cowles Bog was simulated. Table 3 shows that the maximum water-level decline in unit 1 at Cowles Bog, with the "discontinuity" (item 6), is only slightly greater than without the "discontinuity" (item 2). Comparison of figures 15 and 16 indicates that the declines differ significantly at Cowles Bog because of the use of different boundary conditions along the east boundary of the model. However, the simulated declines are nearly identical in the area near the fly-ash ponds despite the boundary condition used. These simulations establish the minimum and maximum model-simulated "reference water levels" in unit 1 at Cowles Bog (table 3).

BEST DOCUMENT AVAILABLE

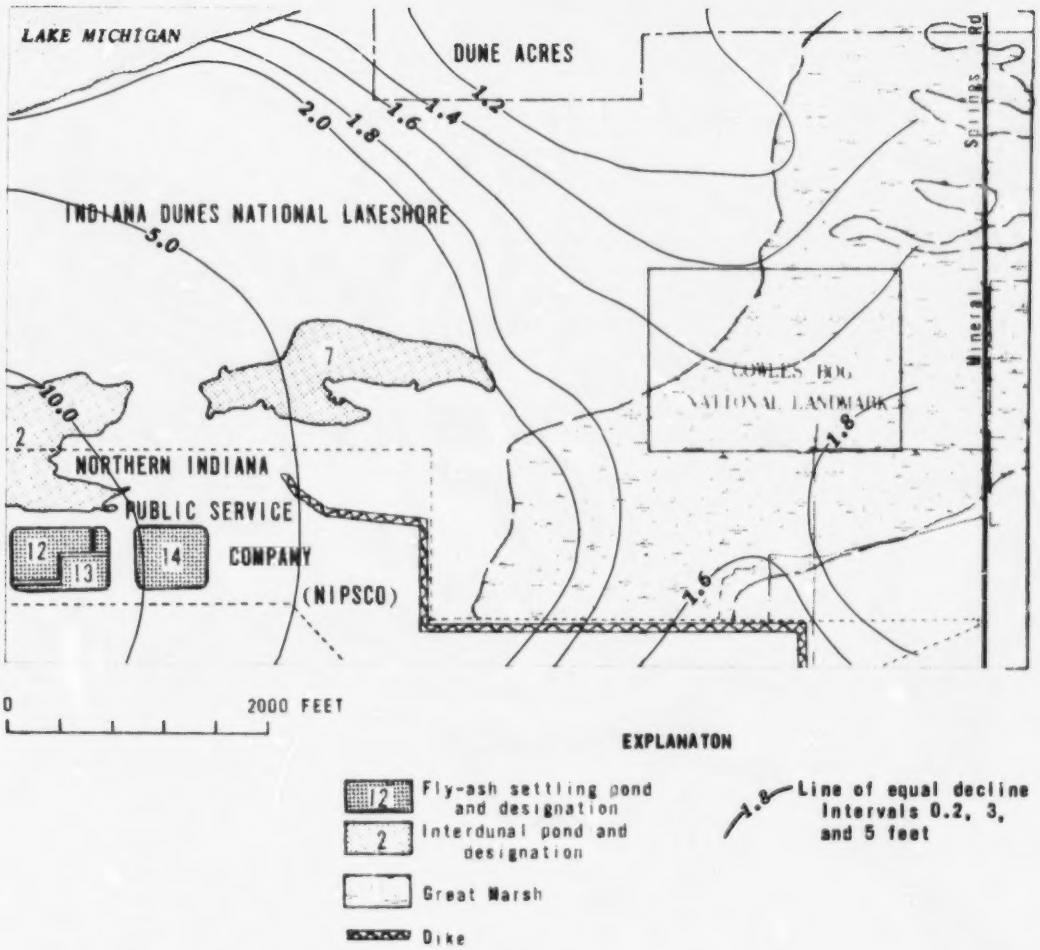


Figure 15.-- Maximum model-simulated water-level declines in unit 1 near Cowles Bog due to decline of seepage mound to equilibrium ; with the '' discontinuity'' in the confining unit.

BEST DOCUMENT AVAILABLE

Table 3.--Simulated effects of construction dewatering and decline of seepage mound on ground-water levels at Cowles Bog: Model node "11, 38"

[National Geodetic Vertical Datum of 1929;CH, Constant-head boundary along east edge of model, units 1 and 3; CF, Constant-flux boundary along east edge of model, units 1 and 3]

Description of model simulation	Water level in unit 1 (ft)		Water level in unit 3 (ft)		Water-level decline in unit 1 (ft)			Water-level decline in unit 3 (ft)			Deviation from "reference water level" in unit 1 (ft)			
					Min		Max	Min		Max	Min		Max	
	CH	CF	CH	CF	CH	CF		CH	CF		CH	CF		
(1) Calibration (Meyer and Tucci, 1979).	------	604.3	-----	605.2	---	---		---	---		----	+1.5		
(2) Experiment A; decline of seepage mound to equilibrium, no dewatering (Meyer and Tucci, 1979).	------	[1]602.8	-----	603.4	---	1.5		---	1.8		----	----		
(3) Experiment S; pumping from unit 1 with seepage mound in place (Meyer and Tucci, 1979).	------	604.0	-----	603.7	---	..3		---	1.5		----	+1.2		
(4) Revised experiment S (pumping from unit 3 with seepage mound in place).	------	604.0	-----	603.6	---	.3		---	1.6		----	+1.2		

BEST DOCUMENT AVAILABLE

(5) Calibration (with "discontinuity" in confining unit at Cowles Bog).	605.0	604.9	605.0	604.9	---	---	---	---	+0.3	+1.6
(6) Repeat of Meyer and Tucci experiments A (constant-flux boundary) and B (constant-head boundary) but with "discontinuity" in confining unit at Cowles Bog; no dewatering.	[1]604.7	[1]603.3	604.7	603.3	0.3	1.6	0.3	1.6	----	----
(7) Revised experiment S (with "discontinuity" in confining unit at Cowles Bog).	604.8	603.7	604.8	603.7	.2	1.2	.2	1.2	+.1	+.4
(8) Revised experiment S (with "discontinuity" and decline of seepage mound, 18 months).	604.6	602.7	604.6	602.7	.4	2.2	.4	2.2	-.1	-.6
(9) Revised experiment S (with "discontinuity" and decline of seepage mound, at equilibrium):										
(a) Without mitigation	604.5	602.0	604.5	602.0	.5	2.9	.5	2.9	-.2	-1.3
(b) With mitigation at 200 gal/min	604.6	602.3	604.6	602.3	.4	2.6	.4	2.6	-.1	-1.0
(c) With mitigation at 400 gal/min.	604.6	602.6	604.6	602.6	.4	2.3	.4	2.3	-.1	-.7

[1]Model-simulated "reference water level."

BEST DOCUMENT AVAILABLE

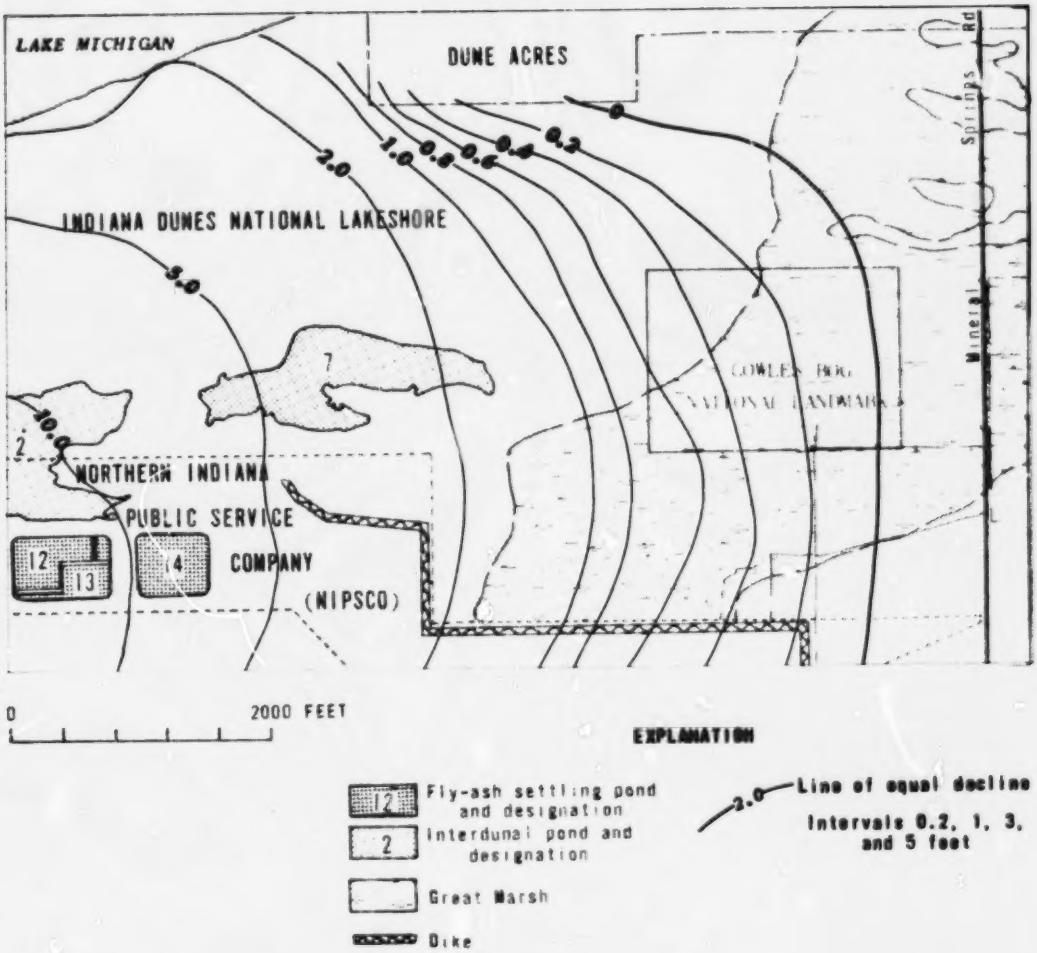


Figure 16.-- Minimum model-simulated water-level declines in unit 1 near Cowles Bog due to decline of seepage mound to equilibrium ; with the "discontinuity" in the confining unit.

To isolate the effects of construction dewatering on water levels in unit 1 near Cowles Bog, the authors simulated the "discontinuity" in the confining unit under Cowles Bog and the conditions of revised experiment S (item 7 in table 3). The simulated maximum and minimum water-level declines in unit 1 for these conditions are shown in figures 17 and 18, respectively. These simulations are analogous to revised experiment S (item 4 of table 3) and revised experiment U (figs. 8 and 9) in that seepage from the fly-ash ponds was allowed throughout the 18-month duration of phase 2 dewatering. Most significant in figures 17 and 18 is the intensification of water-level declines around the area of the simulated "discontinuity" in the confining unit under Cowles Bog. In previous model simulations, in which the "discontinuity" in the confining unit was not considered, such as revised experiments S and U, water-level declines in unit 1 at Cowles Bog were less than declines in unit 3. However, when the "discontinuity" was considered, water-level declines in unit 1 at Cowles Bog were the same as declines in unit 3 because of the good hydraulic connection between the two aquifers. West of the area contoured in figure 17, model-simulated water-level declines are nearly identical with or without consideration of the "discontinuity." Model-calculated rate of pumping from the excavation at the end of each of these simulations was about 742 gal/min.

The effect of construction dewatering with time on water levels at Cowles Bog is illustrated by the simulated maximum water-level declines in figure 19. After 18 months of phase 2 dewatering, the simulation closely approaches equilibrium. Additional water-level declines due to construction dewatering would be very small if phase 2 continued beyond 18 months. Thus, model results indicate that the magnitude of dewatering of unit 1 near Cowles Bog and within the Lakeshore due to pumping from the excavation depends on the relation in time between phase 2 dewatering and the sealing of the fly-ash ponds but not on the duration of dewatering beyond 18 months.

Results of simulation of simultaneous phase 2 dewatering and decline of the seepage mound, with the "discontinuity" in unit 2, are shown in figures 20 and 21 and in item 8 of table 3. In these simulations, phase 2 dewatering and the decline of the seepage mound were continued for 18 months. The simulated water levels are generally above "reference water levels" in the east part of the study area. However, an area of water-level deficiency surrounds the model node where the "discontinuity" in the confining unit was simulated. Table 3 (item 8) shows that the maximum and minimum values for the water-level deficiency are 0.6 and 0.1 ft, respectively. In previous model simulations, where the "discontinuity" was not simulated, the remnant of the seepage mound in the Cowles Bog area after 18 months prevented water-level deficiencies in unit 1. (See fig. 11, revised experiment U with simulated decline of the seepage mound.) However, in the present simulations, water-level declines in unit 1 at Cowles Bog cannot be compensated by the remnant of the seepage mound.

The final series of model simulations are summarized in item 9 of table 3. The series includes simulation of simultaneous phase 2 dewatering and decline of the seepage mound, and with the "discontinuity" in the confining unit 2 at Cowles Bog. The model-simulated water levels and declines shown in item 9a are for a model simulation without mitigation; 9b and 9c are with mitigation. Because of concern that the seepage mound may begin declining

BEST DOCUMENT AVAILABLE

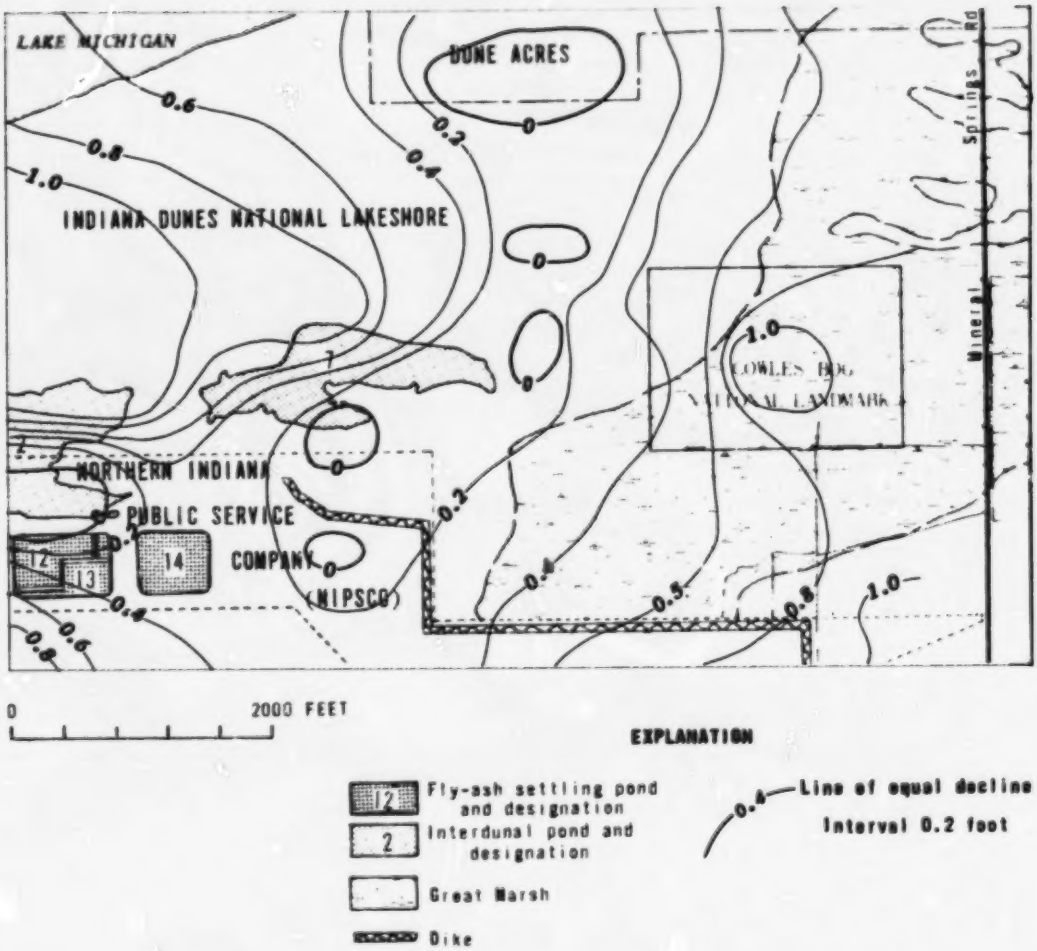


Figure 17.— Maximum model-simulated water-level declines in unit 1 near Cowles Bog after 18 months of phase 2 construction dewatering (revised experiment 5) ; with the "discontinuity" in the confining unit and continuous seepage from the fly-ash ponds.

BEST DOCUMENT AVAILABLE

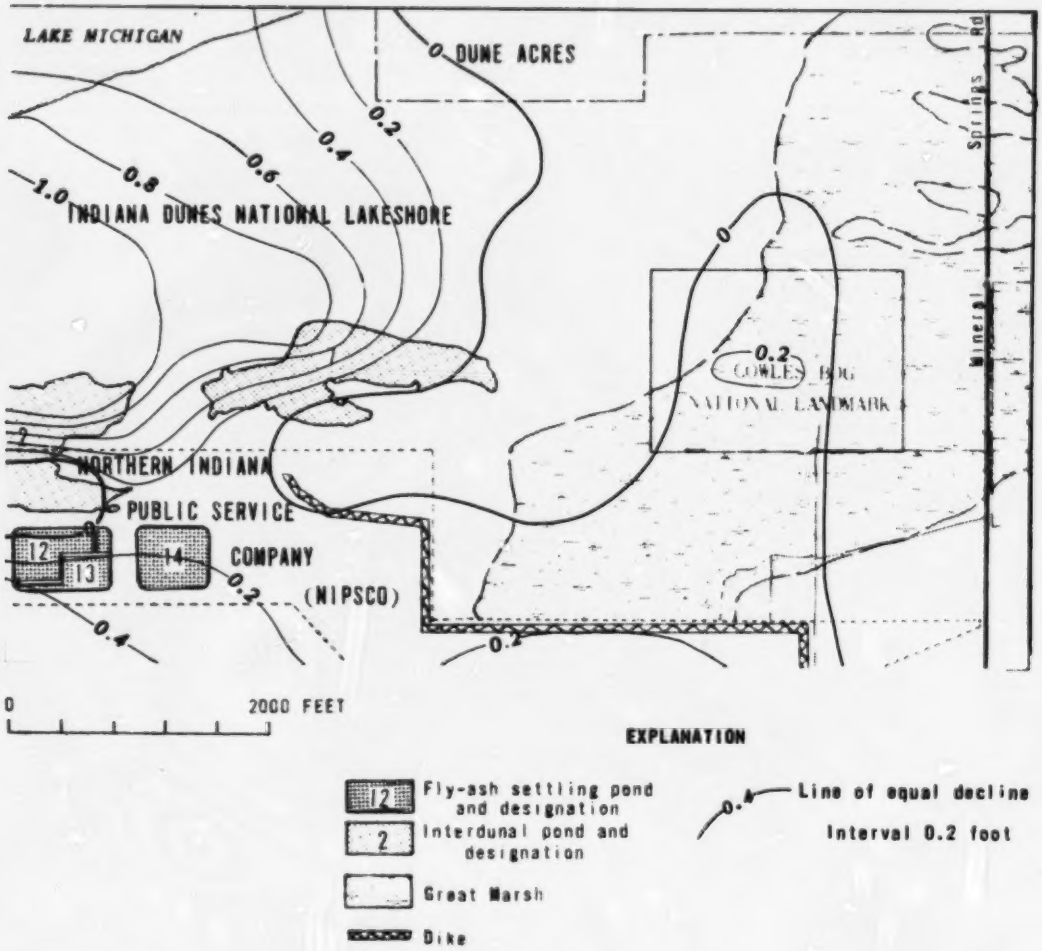


Figure 18.-- Minimum model-simulated water-level declines in unit 1 near Cowles Bog after 18 months of phase 2 construction dewatering (revised experiment S) ; with the "discontinuity" in the confining unit and continuous seepage from the fly-ash ponds.

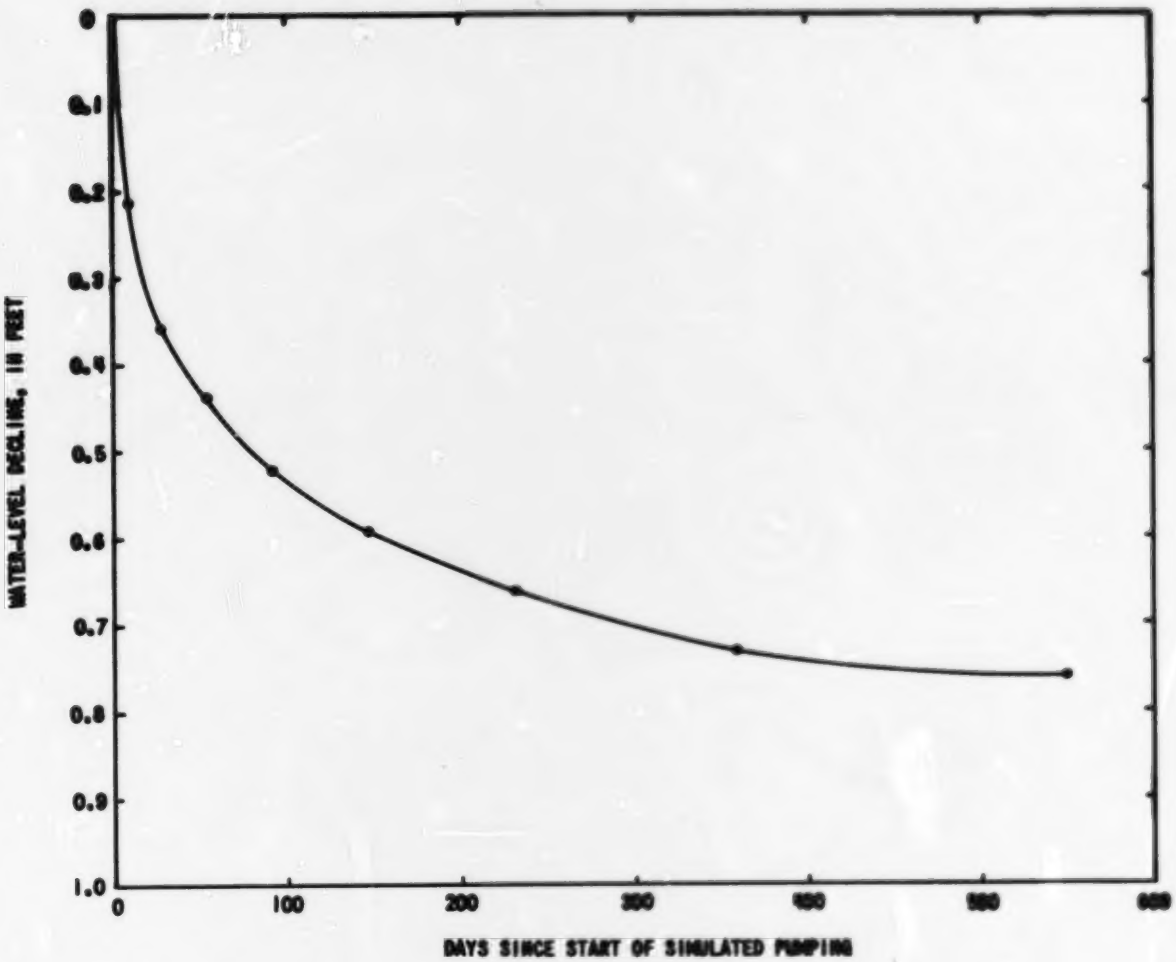


Figure 19.-- Maximum model-simulated water-level declines in unit 1 at model node "11,38" at Cowles Bog due to phase 2 construction dewatering (revised experiment 3); with the "discontinuity" in the confining unit and continuous seepage from the fly-ash ponds.

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

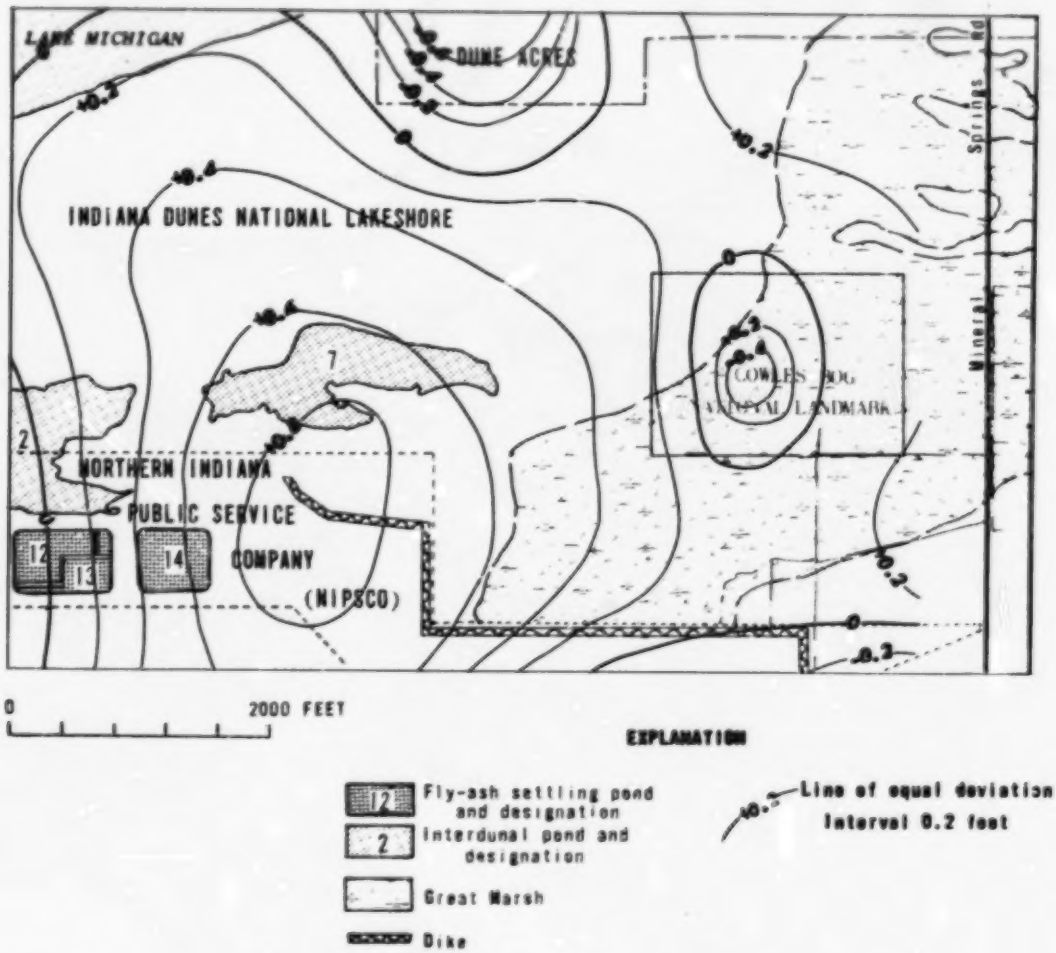


Figure 20.-- Maximum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment 3) and decline of seepage mound; with the "discontinuity" in the confining unit.

BEST DOCUMENT AVAILABLE

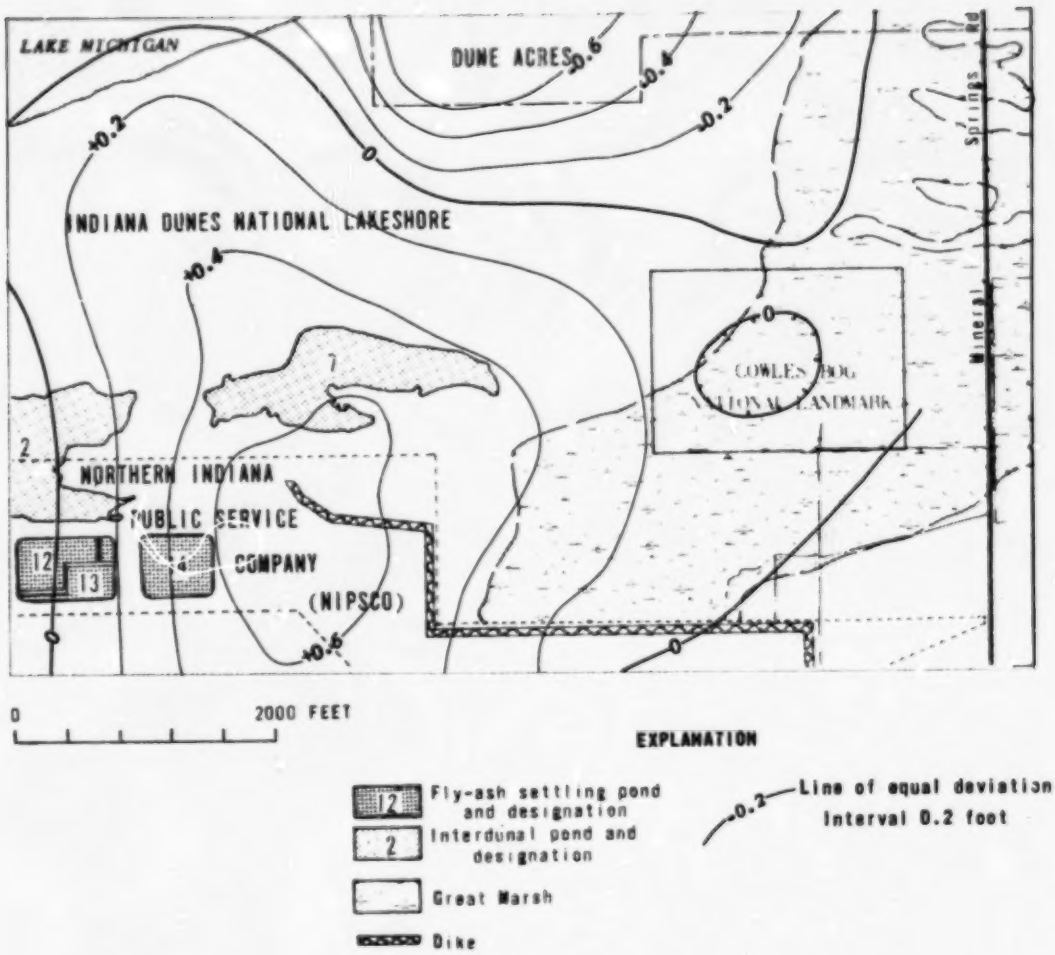


Figure 21.-- Minimum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" after 18 months of phase 2 construction dewatering (revised experiment S) and decline of seepage mound; with the "discontinuity" in the confining unit.

before phase 2 dewatering begins and because figure 19 indicates that water-level declines after 18 months of phase 2 dewatering alone would be insignificant, these simulations were all allowed to proceed to equilibrium conditions. Thus, the results indicated in item 9 include the maximum simulated combined impact of construction dewatering and decline of the seepage mound, and also the impact of construction dewatering alone, at Cowles Bog, with and without mitigation. The maximum simulated water-level decline of 2.9 ft in unit 1 and unit 3 without mitigation is only 0.1 ft more than the sum of maximum water-level declines indicated in items 6 and 7. The water level would have declined the additional 0.1 ft if the simulation in item 7 had reached equilibrium. Therefore, 0.6 of the 0.7-ft difference between the maximum model-simulated water-level declines in items 8 and 9a, represents the remnant of the seepage mound after 18 months. Also the simulated water level in unit 1 at Cowles Bog is between 0.2 and 1.3 ft below the "reference water levels" (water levels in unit 1 for constant-head and constant-flux boundary conditions, item 6 of table 3).

The simulations described in items 9b and 9c of table 3 were the same in every respect as in 9a except that two rates of mitigation (200 and 400 gal/min, respectively), were also simulated. As before, the mitigation rate was applied continuously along with phase 2 dewatering and decline of the seepage mound. Table 3 indicates that. although some of the water-level deficiency at Cowles Bog is made up by the maximum mitigation rate, a deficiency of between 0.1 and 0.7 ft still remains. The reason for the deficiency is probably that the distance between the location of the mitigation and Cowles Bog is too great. The results of the model simulations using a mitigation rate of 400 gal/min (table 3, item 9c) are shown in figures 22 and 23. In these simulations, phase 2 dewatering, decline of the seepage mound, and mitigation at 400 gal/min were all simulated simultaneously and were allowed to proceed to equilibrium. The results indicate a broad area of water-level decline below "reference water levels" in the east half of the study area, including all the marsh area around Cowles Bog.

BEST DOCUMENT AVAILABLE

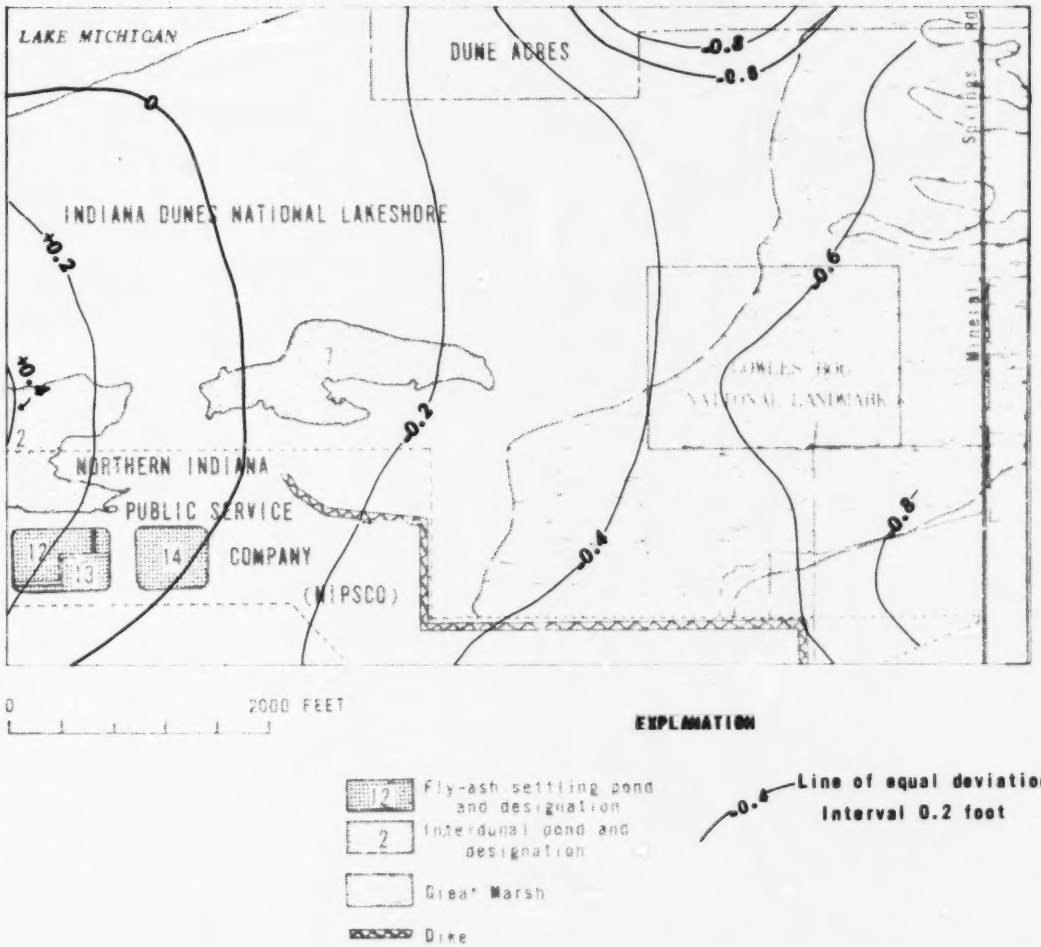


Figure 22.-- Maximum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" for phase 2 construction dewatering (revised experiment S), decline of seepage mound, and mitigation at 400 gal/min, at equilibrium; with the "discontinuity" in the confining unit.

BEST DOCUMENT AVAILABLE

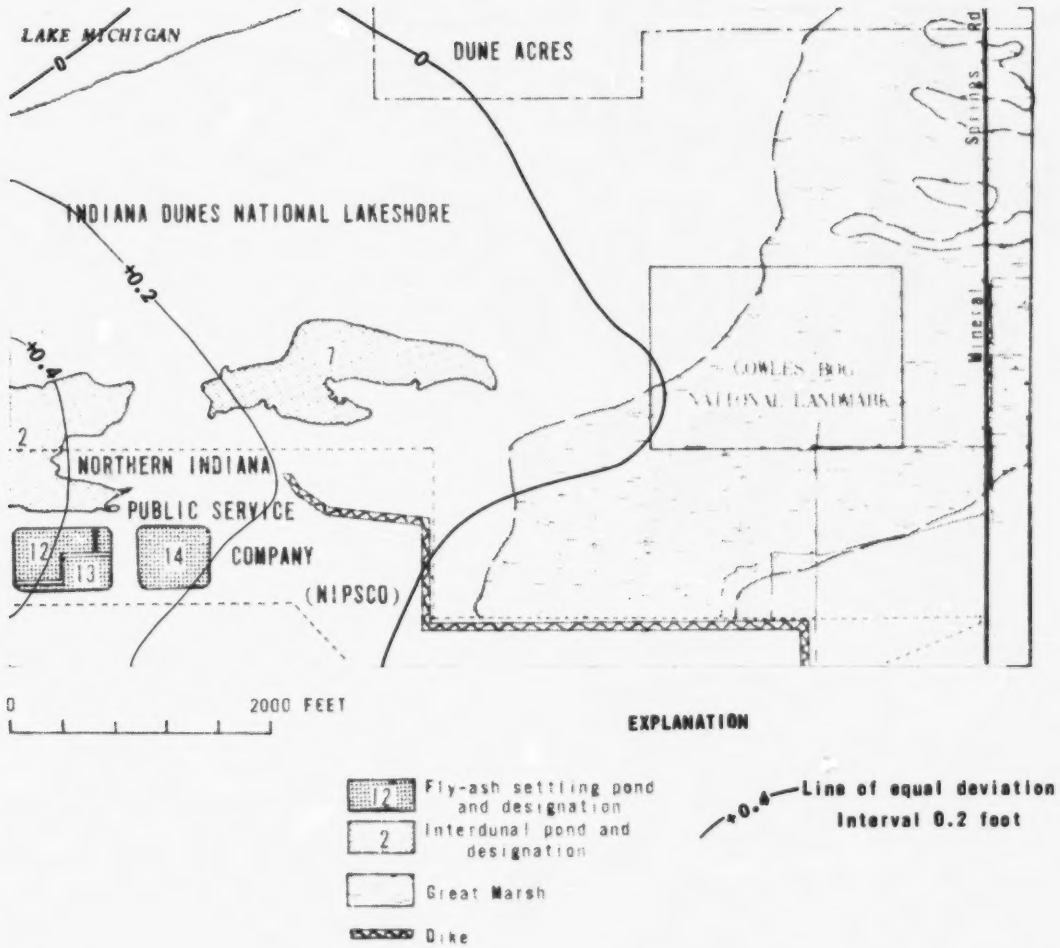


Figure 23.-- Minimum deviation of model-simulated water levels in unit 1 near Cowles Bog from "reference water levels" for phase 2 construction dewatering (revised experiment S), decline of seepage mound, and mitigation at 400 gal/min, at equilibrium; with the "discontinuity" in the confining unit.

SUMMARY AND CONCLUSIONS

Evaluation of data collected at the NIPSCO Bailly site since December 1977 indicates that, of experiments K-Z by Meyer and Tucci (1979, tables 3 and 4), experiments S and U are the ones that best simulate field conditions. These two experiments assumed that the lateral hydraulic conductivity of the slurry wall around NIPSCO's excavation is equal to the design value 2.8×10^{-4} ft/d and that the vertical hydraulic connection between units 1 and 3 under the south one-third of the excavation is good. Model analysis indicates that the vertical hydraulic conductivity of the confining unit between units 1 and 3 under the excavation is a more sensitive parameter than the slurry-wall lateral hydraulic conductivity in the simulation of water levels near the excavation. Further, the good vertical hydraulic connection between units 1 and 3 yields results that are more consistent with field data regardless of what value of the lateral hydraulic conductivity of the slurry wall was used in the simulations.

A model simulation of water-level declines at the NIPSCO-NPS boundary east of the excavation indicates that phase 1 dewatering reaches equilibrium after about 400 days. Model simulation of pumping directly from unit 3 under the excavation for reduction of hydrostatic pressure in that unit yields water-level declines that do not differ significantly from those described by Meyer and Tucci (1979). Simulation of simultaneous intensified phase 2 dewatering and decline of the seepage mound without mitigation indicates that simulated water levels in unit 1 would be below the "reference water levels" within the Lakeshore after 18 months. However, simulations indicate that water levels in unit 1 can be maintained at or above the "reference levels" near the west boundary of the Lakeshore during construction dewatering through continuous application of the maximum design mitigation rate of 400 gal/min.

Recently collected data indicate that a ground-water mound exists in unit 1 at Cowles Bog. The mound is probably produced by the upward discharge of ground water from unit 3 into unit 1 through a "discontinuity" in the confining unit that normally separates the two aquifers. A simulation of water-level decline due to phase 2 dewatering, including the "discontinuity," indicates that phase 2 is close to equilibrium after 18 months in the vicinity of the bog. Simulations also indicate that the "discontinuity" could cause intensified water-level declines in unit 1 at Cowles Bog during phase 2 construction dewatering and that water-level declines below the "reference level" at Cowles Bog cannot be eliminated completely by either the proposed mitigation plan or any remnant of the seepage mound present after 18 months of simultaneous phase 2 dewatering and seepage-mound decline.

Because the flow model has not been verified, it can only be used in a general way to evaluate the effect of construction dewatering and decline of the seepage mound on ground-water levels in and near the Lakeshore. Until the model-simulated estimates of water-level decline can be compared with measured declines, the accuracy of the simulated declines can not be determined. Because of the close proximity of the model boundary to Cowles Bog,

simulation can only yield maximum and minimum estimates of the impact of seepage-mound decline and construction dewatering on the bog. The difference between the maximum and minimum impacts is significant, particularly for simulation of seepage-mound decline. A new expanded model, which places the east boundary farther away from Cowles Bog to eliminate the effects on water levels near the bog, would be needed to refine the estimates of the impact of construction dewatering and seepage-mound decline on water levels in the vicinity of the bog. More field data, detailing the stratigraphy and hydrology of the area, would need to be collected to further refine, calibrate, and verify the model.

REFERENCES

Meyer, William, and Tucci, Patrick, 1979, Effects of seepage from fly-ash settling ponds and construction dewatering on ground-water levels in the Cowles Unit, Indiana Dunes National Lakeshore, Indiana: U.S. Geological Survey Water-Resources Investigations 78-138, 95 p.

Northern Indiana Public Service Company, 1978, Response to Nuclear Regulatory Commission letter of May 19, 1978: Unpublished letter, July 1978, 18 p.

Sargent and Lundy, 1978, Hydrogeologic evaluation of construction dewatering Bailly Generating Station, Nuclear 1: Unpublished report, March 1978, 16 p., 3 tables, 19 exhibits, and appendix A.

Sargent and Lundy, Dames and Moore, and Ground/Water Technology, Inc., 1979, Supplementary information, hydrogeologic evaluation of construction dewatering Bailly Generating Station, Nuclear 1: Unpublished report, August 1979, 28 p., 4 exhibits, and attachment A.

☆ U. S. GOVERNMENT PRINTING OFFICE 1980—654-602